**Ciments Canada Lafarge Ltée**
**Canada Cement Lafarge Ltd.**

# Energy Conservation in the Industrial Minerals Processing Sector Comminution (Crushing and Grinding) Phase III

## Activity 2

Examination, Study and Analysis of the State of
Development or High Efficiency Air Classifiers for
Cement and other Mineral Grinding Circuits

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ACTIVITY 2

Examination, Study and Analysis of the State of Development or High Efficiency Air Classifiers for Cement and other Mineral Grinding Circuits

# ACTIVITY 2
# EXAMINATION, STUDY AND ANALYSIS OF THE STATE OF DEVELOPMENT OF HIGH EFFICIENCY AIR CLASSIFIERS FOR CEMENT AND OTHER MINERAL GRINDING CIRCUITS

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IN THE INDUSTRIAL MINERALS PROCESSING SECTOR
COMMINUTION (CRUSHING AND GRINDING) PHASE III
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# 1.0 EXECUTIVE SUMMARY

The Department of Energy, Mines and Resources (E.M.R.) Canmet in the wish to assist the cement industry and other producers of non-metallic minerals in improving their energy efficiency and to promote research commissioned a study on development of current use of high efficiency air classification equipment.

- The overall objective as stated by E.M.R. was to conduct a literature survey of internationally published literature on the research, development and application of air classification in the production of cement and other industrial minerals.
- To review the literature and prepare a bibliography of the applicable literature.
- To examine current trends and approvals in the application of high efficiency air classification technology in industrial applications.
- To conduct tests, with "state of the art" air classification equipment with ground cement as feed material and;
- To review energy savings realized in cement grinding with grinding circuits employing high efficiency air classification equipment.

## 1.1 Study Objectives

A detailed study on the development and industrial applications of high efficiency air classification in the cement and industrial minerals industry was conducted by I.M.D. Laboratories Ltd. The study consisted of three distinct phases:

- The review of the literature and the preparation of a bibliography of articles pertinent to air classification technology.
- Tests with two "state of the art" air classifiers using cement as the test material.
- The examination of current trends in the application of high efficiency air classification equipment, their method of utilization and benefits derived in terms of improved energy utilization and productivity in the production of cement.

## 1.2 Description of Study Phases

### 1.2.1 Literature Search

A literature search was conducted via keywording using the data bank of the Canadian Institute for Scientific and Technical Information (C.I.S.T.I.) of the National Research Council, Ottawa, Canada.

### 1.2.2 Review of Literature

The literature was reviewed and appropriate articles selected for reference in this study and for preparation of a bibliography on the subject of air classification.

### 1.2.3 Test Program

Tests were conducted, using unclassified discharge from a grinding mill and rejects (oversize) produced by a conventional air classifier operated in closed circuit with this mill. Two types of hign efficiency air classifiers were tested.

### 1.2.4 Application of High Efficiency Air Classifiers

Through contact with equipment manufacturers and users of high efficiency air classifiers in cement grinding, an analysis was conducted of benefits realized in improving performance of cement grinding circuits employing high efficiency air classification equipment. Particular emphasis is given to the reduction of energy consumption. Trends in the methodology of applying high efficiency air classification technology were examined and are discussed in this report.

## 1.3 Concepts of Using High Efficiency Air Classification as a Means of Reducing Energy Consumption in The Comminution of Minerals and Cement.

Air classification is a process that did not receive a great deal of attention for a number of years, until rapid escalation of energy cost in the early 1970's forced companies to assess their energy consumption and implement energy conservation programs.

Up to that point, air classification was more or less ignored as a process that could substantially contribute to efficient utilization of energy consumed in the comminution of minerals and cement.

In general, most of the efforts concentrated on the grinding progress by improving mill control, mill and liner design and use of higher density grinding media. For instance, the use of high chrome, high density grinding balls in cement grinding improved the productivity of cement mills while use of high density fused alumina grinding media improved performance of pebble mills.

Ever increasing demands for closer controlled particle size distributions, increased surface area, finer products, and increased material flow caused air separation equipment to be pushed beyond the limits of their design capabilities.

This resulted in decreased air classification efficiency, allowing large quantities of potential product, not removed during classification, to be returned to the grinding mill for additional, but unnecessary, grinding. The returned material is commonly referred to as "circulating load", or classifier "rejects".

The energy crisis, forced companies to examine their processes with a view of improving energy utilization. Mill operators and manufacturers of air classification equipment alike realized the important function of air classification in the comminution process, and its potential for contributing to energy conservation, productivity and product quality improvement.

This lead to the design and development of a new generation of air classifiers suitable for efficient classification of cements or other ground mineral products.

Data as reported by cement producers and equipment manufacturers indicate production increases in the order of ten (10) to forty (40) percent, with corresponding energy savings.

There are several schools of thought regarding the application and use of these new types of air classifiers. These range from:

- Direct substitution of existing classifiers with the new type classifiers.

- Retrofitting existing classifiers by replacing existing classifier internals with new high efficiency classifying mechanisms.

- The use of two stage air classification by reclassification of rejects from existing classifiers with a high efficiency classifier.

- Two stage classification, in which the existing conventional classifier is used to produce a coarser than required product, but at high volume, followed by a re-classification of the product, with a high efficiency classifier, to produce the desired product.

Each of these methods has its own merit. The final choice or decision is a function of many factors, such as space availability, process control requirements, anticipated downtime, required product characteristics, cost and return on investment (ROI).

In general, the new generation of high efficiency classifiers, offer greatly improved control over product quality, greater operating flexibility, and require less space than conventional air separators.

Actual tests, as conducted with two types of high efficiency air classifiers, using cement mill discharge and rejects from a conventional air separator, show conclusively that they are capable of substantially improving the productivity of grinding and classification systems.

Table 1.1 summarizes these test results. Table 1.2 summarizes reported improvements in cement grinding, after the installation of new high efficiency classifiers.

## 1.4 Conclusions

The use of high efficiency "state-of-the-art" air classification equipment in cement grinding plants, can lead to significant improvements in productivity. While specific levels of improvement are difficult to quantify, due to specific conditions that may exist in any given plant. Increases in productivity, of ten (10) to fifteen (15) percent, appear to be the norm. Energy savings are also significant. Reductions in energy consumption of 3 to 15 kWh/ton of cement produced are reported in published literature.

In addition to productivity gains and energy savings, high efficiency classifiers offer improved process control and therefore reduced product variability.

Rather than replacing existing air separators with new state-of-the-art air classifiers, the concept of two stage classification has shown to have merit. The addition of a high efficiency air classifier to extract additional product from the rejects (oversize) from a conventional air separator may, in some instances, be a convenient and effective approach to achieving the desired objective.

Other than providing much improved classification efficiency, the new types of air classifiers are significantly smaller in physical size, for the same tonnage of material to be classified.

None of the comparisons made, either by direct testwork or from data published in the literature, is to be interpreted as an endorsement of any name brand or type of classifier. Conditions under which data was obtained may vary significantly and should therefore not be used as a direct comparison between any or all types or makes of air classification equipment.

Data as presented is only to show how high efficiency air classification can contribute in a direct and meaningful way to productivity and energy conservation in the production of cement or other mineral products.

Use of high efficiency air classification equipment may also contribute to improved grinding efficiency due to a reduction in fines contained in the rejects from the air classifier. This will minimize overgrinding and/or agglomeration during grinding.

Selection of high efficiency classification equipment should be based on factors, such as:

- demonstrated ability to operate efficiently over a wide range of operating variables and conditions that prevail in the plant where the equipment is to be used;
- design quality and ease of maintenance;
- process control features;
- installed horsepower - estimated kWh/ton of product;
- capital cost.

Table 1.1

## SUMMARY OF TESTS CONDUCTED WITH TWO TYPES OF HIGH EFFICIENCY CLASSIFIERS AT A PILOT SCALE LEVEL

| Feed Material | Classifier Fuller Comp. | Product Yield % | Blaine CM$^2$/Gram |
|---|---|---|---|
| Cement Mill Disch. (1) | O-Sepa | 44.7 | 3664 |
| Cement Mill Disch. (1) | O-Sepa | 40.5 | 3816 |
| Separator Rejects (2) | O-Sepa | 26.9 | 3967 |
| Separator Rejects (2) | O-Sepa | 26.4 | 3697 |
| | Progressive Industries | | |
| Cement Mill Disch. (3) | M-S-5 | 61.6 | 3719 |
| Cement Mill Disch. (3) | M-S-5 | 64.4 | 3786 |
| Separator Rejects (4) | M-S-5 | 39.2 | 3753 |
| Separator Rejects (4) | M-S-5 | 37.9 | 3865 |

Feed Materials - Analysis

(1) Cement Mill Discharge - Blaine 1919 cm$^2$/gram - 54% - 325 mesh

(2) Separator Rejects - Blaine 1254 cm$^2$/gram - 40% - 325 mesh

(3) Cement Mill Discharge - Blaine 2543 cm$^2$/gram - 57% - 325 mesh

(4) Separator Rejects - Blaine 1717 cm$^2$/gram - 45% - 325 mesh

Note: These tests were not made to compare two different classifiers but rather to test their individual performance using different quality of feed materials.

Table 1.2

## SUMMARY OF IMPROVEMENTS IN PRODUCTIVITY OF CEMENT GRINDING MILLS FOLLOWING INSTALLATION OF HIGH EFFICIENCY AIR CLASSIFICATION EQUIPMENT

| Classifier | Production Rate tph | Specific Energy Consumption kWh/t | Product Blaine | Ref. # |
|---|---|---|---|---|
| Conventional | 14.0 | 55.0 | 4100 | C-3 |
| O-Sepa | 17.3 | 51.6 | 4100 | |
| Conventional | - | 43.2 | 3400 | C-3 |
| O-Sepa | - | 34.8 | 3240 | |
| Conventional | 65.9 | 52.5 | 3809 | |
| O-Sepa | 85.0 | 39.7 | 3700 | |
| O-Sepa | 90.7 | 38.7 | 3577 | |
| Conventional | 23 | - | 3850 | C-4 |
| Sturtevant-SD | 40 | - | 3610 | |
| Conventional | 38.0 | 52.3 | 4100 | C-7 |
| Polysius Cyclopol | 46.7 | 48.4 | 3820 | |
| Polysius Cyclopol | 45.7 | 46.2 | 3910 | |
| Conventional | 17 | 71 | 4400 | C-7 |
| Polysius Cyclopol | 25 | 51 | 4150 | |
| Conventional | 42 | 46.3 | 3600 | |
| Sturtevant SD | 48 | 40.5 | 3680 | |
| Conventional | 94 | 40.8 | 3870 | |
| Polysius Cyclopol | 108 | 37.1 | 3870 | |

## 1.0 RESUME DU PROGRAMME DIRECTEUR

Le Centre CANMET, qui relève du ministère de l'Energie, des Mines et Ressources (E.M.R.), a commandé cette étude sur l'utilisation de séparateurs à air à haute efficacité pour assister l'industrie cimentière et les autres producteurs de minerais non métalliques à améliorer l'efficacité énergétique de leurs installations, et promouvoir la recherche dans ce domaine.

o L'objectif d'ensemble établi par E.M.R. était de réaliser une étude de la documentation publiée dans le monde entier sur le développment et l'utilisation de la classification par air dans la production du ciment et autres minerais industriels.

o D'évaluer la documentation et de préparer une bibliographie des documents retenus.

o D'étudier les tendances et les approbations relatives aux techniques de classification par air en milieu industriel.

o De réaliser des essais avec des équipements de classification modernes en utilisant le ciment comme matériau d'alimentation.

o D'évaluer les économies réalisées pour le broyage du ciment dans les circuits de broyage munis d'équipement de classification par air à haute efficacité.

### 1.1 Objectifs de l'étude

Les laboratoires I.M.D. Ltd ont réalisé une étude approfondie du développement et des applications industrielles des techniques de classification par air dans l'industrie du ciment et des minerais industriels. Cette étude comportait trois phases distinctes:

o Analyse de la documentation existante et la préparation d'une bibliographie des articles traitant des techniques de classification par air.

o Essais avec deux séparateurs à air à haute efficacité en utilisant le ciment comme matériau pour les tests.

## 1.1 Objectifs de l'étude (suite)

- o Etude des tendances actuelles pour l'application de séparateurs à air à haute efficacité, les méthodes d'utilisation et les avantages qu'ils procurent en matière d'économie d'énergie et d'amélioration de la productivité dans l'industrie du ciment.

## 1.2 Description des phases de l'étude

### 1.2.1 Recherche documentaire

La recherche documentaire est été réalisée en utilisant la technique du mot-clé, grâce à la banque de données de l'Institut canadien de l'information scientifique et technique, qui relève du Conseil national de recherche à Ottawa.

### 1.2.2 Analyse de la documentation

On a analysé la documentation et sélectionné les articles se rapportant à cette étude afin d'établir une bibliographie de la classification par air.

### 1.2.3 Programme d'essais

Les essais ont été réalisés avec la décharge non classifiée d'un broyeur et les rejets (surdimentionnés) produits par un séparateur à air conventionnel utilisé en circuit fermé avec le broyeur. Deux types de séparateurs à haute efficacité ont été étudiés.

### 1.2.4 Utilisation des séparateurs à air à haute efficacité

Les renseignements recueillis auprès des manufacturiers et des utilisateurs de séparateurs à air à haute efficacité ont permis d'évaluer les bénifices obtenus grâce à l'amélioration des circuits de broyage munis de ce type de séparateur. Le présent rapport traite plus particulièrement des économies d'énergie et souligne les nouvelles méthodes d'utilisation de séparateurs à air à haute efficacité.

## 1.3 Utilisation de séparateurs à air à haute efficacité pour réduire la consommation d'énergie dans la fragmentation des minérais et du ciment.

La classification par air est un procédé qui a soulevé peu d'intérêt durant un certain nombre d'années, tout au moins jusqu'à l'augmentation rapide des coûts d'énergie du début des années '70, alors que les sociétés se sont vues obligées d'évaluer leur consommation d'énergie et de mettre en place des programmes d'économie.

La classification par air n'était jusqu'alors pas considérée comme un procédé capable de contribuer à une réduction sensible de la consommation d'énergie pour la fragmentation des minerais et du ciment.

En règle générale, les efforts techniques consistaient à améliorer le procédé de broyage en perfectionnant le contrôle du broyeur, la conception des blindages et des broyeurs, et en augmentant la densité des corps broyants. Ainsi, l'utilisation de boulets de broyage à haute teneur en chrome et à haute densité a permis aux cimenteries d'améliorer leur productivité, alors que l'emploi de corps broyants à base d'alumine fondue à haute densité a permis d'améliorer l'efficacité des broyeurs à galets.

Cependant les demandes sans cesse croissantes pour un meilleur contrôle de la granulométrie, l'augmentation de la surface, des produits plus fins et un débit plus élevé, ont eu comme effet de pousser les équipements de classification au delà de leurs limites conceptuelles.

Il en est résulté une réduction de l'efficacité de la classification par air et le renvoi au broyeur d'importantes quantités de produit (non éliminé durant la classification) pour un second broyage inutile (dans l'industrie du ciment on nomme ce produit la "charge en circulation").

La crise de l'énergie a obligé les sociétés à ré-évaluer leur procédé afin d'améliorer leur consommation énergétique. Les utilisateurs et les fabricants de séparateurs à air ont pris conscience de l'importance de la classification par air dans le processus de fragmentation, et de son potentiel tant au niveau des économies d'énergie que de l'amélioration de la productivité des séparateurs à air à haute efficacité.

Cette prise de conscience a mené à l'étude et à la mise au point d'une nouvelle génération de séparateurs à air qui conviennent à la classification du ciment et des autres minerais soumis au broyage.

Les données fournies par les producteurs de ciment et les manufacturiers d'équipement indiquent que le recours aux nouvelles techniques permet d'augmenter la production de 10 à 40 pour cent et de réaliser des économies d'énergie correspondantes.

Il existe plusieurs écoles de pensée relatives à l'utilisation de ces séparateurs à air à haute efficacité. Elle varient entre:

- Le remplacement pur et simple des séparateurs existants par des séparateurs à haute efficacité.

- La modernisation des séparateurs existants grâce au remplacement des mécanismes internes par des mécanismes à haute efficacité.

- La classification en deux étapes où les rejets des séparateurs existants sont traités à nouveau dans les séparateurs à haute efficacité.

- La classification en deux étapes qui consiste à utiliser d'abord le séparateur existant pour fabriquer un produit plus grossier que la taille désirée - mais en grandes quantités, puis à re-classifier le produit dans un séparateur à haute efficacité pour obtenir la finesse requise.

Chacune de ces méthodes a ses mérites. Le choix final doit tenir compte de nombreux facteurs tels que: l'espace disponible, le processus de contrôle, les prévisions d'arrêts, les caractéristiques du produit, les coûts d'investissement et le rendement du capital investi.

En règle générale, la nouvelle génération de séparateurs à air à haute efficacité permet de mieux contrôler la qualité du produit et demande moins d'espace que les séparateurs conventionnels.

Des essais réalisés avec les deux types de séparateurs à air à haute efficacité, au cours desquels on a utilisé la décharge et les rejets d'un séparateur conventionnel, ont démontré de façon concluante que ces types de séparateurs peuvent améliorer substantiellement la productivité des systèmes de broyage-classification.

Le tableau 1.1 présente un sommaire des résultats de ces essais, alors que le tableau 1.2 résume les améliorations obtenues dans les cimenteries suite à l'installation des séparateurs à haute efficacité.

## 1.4 Conclusion

L'utilisation, par les cimenteries, d'équipement moderne de classification à haute efficacité peut conduire à des améliorations sensibles de la productivité du système. Bien qu'il soit difficile de quantifier les niveaux d'amélioration de façon spécifique en raison des circonstances particulières à chaque cimenterie, la norme semble être une augmentation de la productivité de dix (10) à quinze (15) pour cent. Les économies d'énergie sont également importantes. La documentation disponible indique une diminution de la consommation énergétique de l'ordre de 3 à 15 kWh par tonne de ciment produit.

Outre les améliorations de la productivité et les économies d'énergie, les nouveaux types de séparateurs offrent un meilleur contrôle du procédé et réduisent les variations de finesse du produit.

## 1.4 Conclusion (suite)

Plutôt que de remplacer les séparateurs à air existants par des séparateurs modernes, le concept de la classification en deux étapes s'avère être une solution intéressante. Le recours à un séparateur à air à haute efficacité pour extraire des quantités additionnelles des rejets (surdimensionnés) provenant d'un séparateur conventionnel peut, dans certains cas, constituer un moyen pratique et efficace d'atteindre l'objectif recherché.

En plus d'améliorer l'efficacité de la classification, les nouveaux séparateurs à air sont beaucoup moins encombrants pour les mêmes débits de matière à classer.

Aucune des comparaisons établies à partir d'essais directs ou de données connues ne doit être interprétée comme étant une recommandation en faveur d'une marque ou d'un type de séparateur particulier. Les circonstances dans lesquelles les données ont été recueillies varient de façon significative, celles-ci ne doivent pas faire l'objet de comparaison directe entre les divers types et les différentes marques d'équipement de classification.

Les données présentées ont pour seul but de démontrer à quel point la classification par air à haute efficacité peut contribuer à l'amélioration du broyage et à réduire la consommation énergétique dans les cimenteries.

L'utilisation d'équipement de classification par air à haute efficacité peut également contribuer à améliorer l'efficacité du broyage, en raison de la réduction de la quantité de fines contenues dans les rejets du séparateur à air, et ainsi éliminer le surbroyage et/ou l'agglomération en cours de procédé.

Le choix d'équipement de classification devrait être basé sur des facteurs tels que:

- l'aptitude prouvée à fonctionner efficacement dans la gamme de conditions opératoires et des circonstances qui prévalent à l'usine où l'équipement doit être utilisé;
- la qualité de la conception et la facilité d'entretien;
- les éléments de contrôle du procédé;
- la puissance installée, et la consommation estimée en kWh/tonne de produit;
- les coûts d'investissement.

## TABLEAU 1.1

## SOMMAIRE DES ESSAIS EFFECTUES AVEC DEUX TYPES DE SEPARATEURS A HAUTE EFFICACITE AU NIVEAU D'ECHELLE PILOTE

| Matériau d'alimentation | Séparateur | Produit Net en % | Blaine cm$^2$/gramme |
|---|---|---|---|
| | Fuller Company | | |
| Décharge de broyeur à ciment (1) | O-Sepa | 44.7 | 3664 |
| Décharge de broyeur à ciment (1) | O-Sepa | 40.5 | 3816 |
| Rejets du séparateur (2) | O-Sepa | 26.9 | 3967 |
| Rejets du séparateur (1) | O-Sepa | 26.4 | 3697 |
| | Progressive Industries | | |
| Décharge de broyeur à ciment (1) | M-S-5 | 61.6 | 3719 |
| Décharge de broyeur à ciment (1) | M-S-5 | 64.4 | 3786 |
| Rejets du séparateur (2) | M-S-5 | 39.2 | 3753 |
| Rejets du séparateur (1) | M-S-5 | 37.9 | 3865 |

### Analyse des matérieux d'alimentation

(1) Décharge de cimenterie - Blaine 1 919 cm$^2$/g - 54% - 325 mesh
(2) Décharge du séparateur - Blaine 1 254 cm$^2$/g - 40% - 325 mesh
(3) Décharge de cimenterie - Blaine 2 543 cm$^2$/g - 57% - 325 mesh
(4) Décharge de séparateur - Blaine 1 717 cm$^2$/g - 45% - 325 mesh

Nota: Ces essais n'avaient pas pour but de comparer des séparateurs différents mais plutôt de contrôler l'efficacité de chacun en utilisant divers matériaux d'alimentation.

## TABLEAU 1.2

### SOMMAIRE DES AMELIORATIONS DE PRODUCTIVITE OBTENUES SUR DES BROYEURS CIMENT SUITE A L'INSTALLATION D'EQUIPEMENT DE CLASSIFICATION PAR AIR A HAUTE EFFICACITE

| Séparateur | Taux de production (t/h) | Consommation énergétique en kWh/t | Produit Blaine | Numéro de référence |
|---|---|---|---|---|
| Conventionnel | 14,1 | 55,0 | 4100 | C-3 |
| O-Sepa | 17,3 | 51,6 | 4100 | |
| Conventionnel | -- | 43,2 | 3400 | C-3 |
| O-Sepa | -- | 34,8 | 3240 | |
| Conventionnel | 65,9 | 52,5 | 3809 | |
| O-Sepa | 85,0 | 39,7 | 3700 | |
| O-Sepa | 90,7 | 38,7 | 3577 | |
| Conventionnel | 23 | -- | 3850 | C-4 |
| Sturtevant-SD | 40 | -- | 3610 | |
| Conventionnel | 38,0 | 52,3 | 4100 | C-7 |
| Polysius Cyclopol | 46,7 | 48,4 | 3820 | |
| Polysius Cyclopol | 45,7 | 46,2 | 3910 | |
| Conventionnel | 17 | 71 | 4400 | C-7 |
| Polysius Cyclopol | 25 | 51 | 4150 | |
| Conventionnel | 42 | 46,3 | 3600 | |
| Sturtevant-SD | 48 | 40,5 | 3680 | |
| Conventionnel | 94 | 40,8 | 3870 | |
| Polysius Cyclopol | 108 | 37,1 | 3870 | |

## 2.0 INTRODUCTION

The Canadian Industry Program for Energy Conservation (CIPEC) reported a fifteen (15) percent reduction in energy consumption per tonne of output in 1982, compared to the base year 1974. Much of this saving could be attributed to improved housekeeping. Achieving further conservation would require process modification and fuel switching; both require Research and Development (R&D). The areas for work were grouped as follows:

| | |
|---|---|
| General R&D | applicable to industrial mineral processing in general |
| Cement R&D | processing of Portland and other hydraulic cements and gypsum plaster, |
| Clay products R&D | applicable to manufacture of brick, tile, pipe, etc. |

The Department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations, commissioned this study.

The overall objective as stated by EMR was:

> To develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

EMR defined direct and indirect energy consumption in the following way:

> Direct energy consumption measured the work done during the crushing and grinding operations and is expressed in kWh/tonne.
>
> The indirect energy consumption is less frequently recognized and harder to quantify. Its effects are felt during secondary processing or utilization of comminuted materials. The correct size distribution of cement for example could command savings of up to ten (10) percent of the amount of cement necessary to make concrete. Optimization of comminution both in terms of kWh/tonne and in terms of processing energy consumption would make a major contribution to energy conservation in the industrial minerals processing sector.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

## Phase 1 - Plant Studies to Develop a Data Base

For each mineral, studies were made of power consumption during comminution at a plant whose operations are typical of the industry. The results are from a brief investigation of the company's operations and therefore, are descriptive rather than analytical.

## Phase II - Establishment of Monitoring Methodology

An evaluation was made of commercially available particle size measuring equipment with a view to establishing the feasibility of mill circuit control by on-line particle size measurements.

Also under this phase, a proposal for a pilot plant test program was developed.

### Phase III - Pilot Plant Studies of Comminution Related to Industrial Minerals and Energy Consumption.

This report is presented in accordance with Phase III, Activity I of the study on "Energy Conservation in the Industrial Mineral Sector - Comminution" for Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada (EMR).

Witteck Development Inc. of Mississauga, Ontario and I.M.D. Laboratories Ltd. of Toronto, were responsible for Activities 1, 2, 3, 4, 6, 7 and 8 of the Phase III programme. The activities include the following:

| | |
|---|---|
| Activity 1 | Examination of the performance of a "state of the art" high efficiency classifier in a conventional milling circuit. |
| Activity 2 | Examination, study and analysis of the state of development of classifiers for cement grinding circuits. |
| Activity 3 | Examination of the use of grinding aids and anti-static agents in dry grinding circuits. |
| Activity 4 | Monitoring and control of a dry grinding circuit using a particle size analyzer and programmable controllers. |
| Activity 6 | Evaluation of the use of dry autogenous grinding of silica to produce coarse size sand grade product. |
| Activity 7 | Development of the necessary technology to optimize the comminution of mica. |

Activity 8 To evaluate various attrition mills to best produce rounded grained sand suitable for foundry sand applications.

This report presents the results of a review and pilot plant testing of the state of development of high efficiency air classification equipment and their application in the production of cements and other fine ground industrial minerals. Data is presented at several levels of detail.

- A Summary containing a general review of the state of the art in the development of high efficiency air classifiers.

- Detailed discussion, outlining study objectives.

  Detailed discussion
  - Study objectives
  - History of development of air classification equipment
  - Review of published literature on re-development and evaluation of high efficiency air classification equipment.
  - Application and methodology for use of high efficiency air classifiers in cement and other industrial mineral production.
  - Actual tests with cement on two types of high efficiency air classifiers.

Review of improvements in productivity and energy conservation achieved by the installation of high efficiency classification equipment in cement grinding circuits.

Preparation of a bibliography of published literature on the theoretical and practical aspects of air classification technology.

Working papers resulting from the above activities which are available for consultation.

## 3.0 OBJECTIVES

This report examines the development and application of high efficiency air classification equipment in production of cements and other fine ground industrial mineral products. Improvements in productivity and reduced energy consumption resulting from their use in cement production is discussed.

The objectives were achieved by completing the following study and test phases:

3.1 A literature search and review of published articles, and patents on the development, evaluation and application of high efficiency air classification equipment in the grinding of cement and other industrial mineral products.

3.2 Conducting classification tests, with two types of high efficiency air classifiers, using cement mill discharge and rejects from a conventional air separator (as used by the cement industry) as feed material. Analyzing the results of these tests with respect to classifier performance, productivity and energy savings.

3.3 Reviewing trends and impact, of the use of high efficiency air classifiers on productivity gains and energy savings.

3.4 Examining the methodology of using high efficiency air classification, such as two-stage air classification.

3.5 Preparing a bibliography of pertinent articles on the practical and theoretical considerations regarding development, evaluation and utilization of high efficiency air classification equipment.

## 4.0 REVIEW OF LITERATURE

A literature search was conducted using appropriate key-wording to access pertinent articles on the subject of high efficiency air classification technology with particular emphasis on their development, evaluation and application in the production of cement and other non-metallic mineral products.

The search was conducted via computer using the data bank of the Canadian Institute for Scientific and Technical Information (C.I.S.T.I.) of the National Research Council in Ottawa, Canada.

Published literature, augmented by articles, brochures and product catalogues as provided by manufacturers of high efficiency air classification equipment was reviewed, for the purpose of examining the "state of the art" in air classification, benefits realized by users of high efficiency air classifiers and the various concepts or methodology of their utilization in closed circuit grinding operations or as a separate, dedicated unit operation in the production of fine mineral powders.

### 4.1 History of Air Classifications

The use of air classification dates back to 1885 when a patent was granted to Mumford and Moodie for an air separator. This early separator functioned by feeding solids onto a rotating distributor plate, the solids being exposed to a rising air stream. Coarse particles, not suspended by the air flow would drop out in to an inner core, while the fines entrained in the air stream would rise and separate from the air in an expansion chamber. This early separator can be called a gravity separator, as it utilizes the principle of the differing settling velocities for particles of different size, density or shape.

Today air classification is an important tool used extensively in agriculture, food production, waste treatment and disposal, chemicals and by the mineral resource industry in the production of a wide range of ground mineral products.

Air classification is a process analogous to screening when used to separate particles on the basis of size. Practical and economic limitations of screening resulted in the development of sizing devices that could accomplish this task. Air classification is not as finite or efficient in making size separations as is possible by screening. Early separators did not exhibit high separating efficiency characteristics due to their simplicity of design. Their primary use was in dedusting large volumes of mineral or agricultural products.

For many years following the first reported use of an air separator, industry did not avail themselves of this technique and very few air separators were in use. It was not until 1919 that Sturtevant manufactured its first air separator for use by the tobacco industry.

In the late 1920's, the cement industry found that by using air separators in closed circuit with grinding mills, production could be increased by twenty five percent (25%) or more without an appreciable increase in power consumption. At that time cement producers measured fineness by the use of a 200 mesh (74 micron) sieve and an accepted cement quality was in the order of 94-95% passing this size.

By today's standards, Type I cement now averages 94-95% passing 325 mesh (45 micron) with a Blaine surface area of 3700 $cm^2$/gram. High early strength cements have Blaine surface areas in the range of 5000-6000 $cm^2$/gram.

Demand for products of controlled particle size & Blaine surface area necessitated increased process control over particle size.

Similar events occurred in the production of other non-metallic minerals. This industry was faced not only with demands for better controlled mineral products but also for ever finer products in order to satisfy requirements of the ceramics, paints and plastics industry.

No significant activity in classifier development, other than refinement took place until the escalation of energy costs in the early nineteen seventies. This, plus the increased demands for finer and closely controlled products, caused companies to examine their energy utilization and process efficiency. Energy conservation became a widespread practice in all fields of technology, with companies establishing specific departments charged with examining means of energy conservation.

Examination of the energy efficiency of grinding and classification processes disclosed that the requirements for closely controlled and finer products had resulted in a significant drop in classification efficiency. In essence, producers were faced with having to use classification devices developed for much less critical applications then they now faced. Milling circuits were upgraded by improving control over milling parameters, changes in mill design, use of grinding aids and grinding media of higher density. This resulted in increased grinding efficiency leading to higher volumes of mill discharge. This caused overloading of the air classifiers with a corresponding reduction in classification efficiency, partly negating the improvements in grinding efficiency. Rejects from air classifiers, i.e. the oversize contained large amounts of potential product which was returned to the mill for additional grinding. This could only be corrected by installation of additional or improved classification equipment. This fact was recognized by producers of cement, other industrial minerals and manufacturers of air classification equipment.

This recognition was the driving force providing the impetus for significant activity in the development of improved air classification equipment and research into air classification as an important process function in the comminution process. The contribution that high efficiency air classification could make to energy conservation and productivity improvements was considered significant.

Design and development of air classification equipment became a more scientific process as it took cognizance of the aerodynamic properties of particles, placing the design process on a more scientific footing.

This research and development resulted in a number of new air classifiers specifically designed for the production of cement and fine mineral powders. For the purpose of this study, these new air classifiers will be identified as high efficiency air classifiers, as distinct from the terms air classifier or air separator, denoting equipment of older design and capabilities.

### 4.2 General Discussion on Air Classification

The use of air classification technology for production of products with closely controlled particle size distributions has increased significantly in importance over the last two decades. The need for ever finer products and closer control of particle size distributions, coupled with the need to achieve better energy efficiency in grinding operations has resulted in a critical examination of the function of air classification as a unit operation. As a result, air classification as a process has been exhaustively examined with a view of improving its operational efficiency.

This lead to the design and development of a new generation of air classifiers in which particle aerodynamics, drag forces and other theoretical aspects of particle behaviour were considered in the design process. As a result, air classification is now considered of significant importance in the process of achieving optimum productivity and effective energy utilization in the dry grinding of cement & other mineral products.

Implementation of "purpose" designed air classification equipment has resulted in a significant contribution to improved product quality, system productivity and capability for producing superfine mineral products.

Air classification is a term used to describe a process in which particles suspended in a gas stream, usually air are subjected to and influenced by forces to move the particles in two different directions, depending on physical characteristics such as size, density or shape.

Forces that effect particle movement are the viscous drag of the air to move a fine particle in one (upward) direction and the force of gravity, inertia, or applied centrifugal force which causes a coarse particle to move in a different (sideways) direction.

There are two laws governing movement of particles in an air stream, Stokes law of sedimentation velocity in viscous fluids and Newton's Law of Motion. Stokes law applies to low Reynolds numbers while Newton's law applies at high Reynold's numbers.

By suspending ground particles in a moving air stream, fine particles are primarily influenced by the viscous drag of the air, while coarser particles are affected by inertia forces or applied centrifugal forces. This allows fine particles to be conveyed by the air stream to a point outside the classification zone, while coarser particles will drop out of the air stream or are placed in a different particle trajectory by centrifugal forces.

These in simplified form are the basic, theoretical considerations of how air classification works. De Silva(1) gives an excellent review of the theory of air classification.

Factors other than purely theoretical considerations will affect how well a classifier will perform and the level of separation efficiency that can be achieved.

These can be quaified as follows:

- Material to be classified must be well dispersed and free of agglomerates.
- Feed rate must be closely controlled.
- Overloading a classifier leads to poor selectivity in separation due to physical entrapment of particles preventing them to travel in the trajectory dictated by its mass. This results in fine particles (of product size) to be diverted from their theoretical

path in the air or gas stream and results in fine particles reporting in the oversize fraction.

- For each feed material of a given particle size distribution and each specific product requirement, there is an optimum feed rate that will result in effective separation. This optimum feed rate must be determined experimentally, for each product, each type of feed, and type of air classifier employed.

- The particle size distribution of material to be classified is of importance. Feed material with steep size distributions are more difficult to classify, because of a high concentration of "near size" material of similar mass at the cut point, irrespective of where the cut point is in the size distribution.

- At the other end of the spectrum, feed materials with high levels of "product sized" particles are also difficult to classify efficiently due to high surface area, increased difficulty of dispersing the material and greater potential for physical displacement of fine particles. These effects can be minimized by operating at lower feed rates, in order to maintain high classifier efficiency.

- In general, for any given material to be classified, i.e. mineral or cement with a specific size distribution, there is an optimum feed rate (and other controllable separating parameters) that will result in optimum classifier efficiency. This point can be readily established by conducting a series of experiments. It must be noted that optimum classification efficiency does not necessarily mean optimum product characteristics or performance.

## 4.3 TYPES OF AIR CLASSIFICATION EQUIPMENT

Air classification equipment can be divided into three distinctive types with each type having its own area of application.

These types are:

- o Gravity separators
- o Spiral or centrifugal separators
- o Dispersion type classifiers

### 4.3.1 Gravity Separators

This type of classifier includes gravity counterflow and cross flow separators. It is the simplest form of classifier used primarily in dedusting granular products or cleaning grain products.

These types of air classifiers have high inherent capacity and are used in the particle size range of 100 to 2000 micron.

The mode of operation is based on distributing material to be classified via a rotating distributor plate into a classifying chamber. In this chamber, particles are subjected to a counterflow of air, allowing fines to become airborne in the air stream, removed from the classifier and separated from the air by a cyclone or dust collector. Coarse particles not suspended in the airstream are thrown sideways by the centrifugal action of the rotating distributor plate. Because of their greater mass or density, coarse particles will descend against the rising air stream and are removed via a discharge port in the bottom of the classifier.

Control over separation is by virtue of rotational speed of the distributor plate and/or by the velocity of the rising air stream.

Gravity separators typically operate in open circuit. Their primary function is in the removal of unwanted dust, i.e. fines, with the coarse fraction being the desirable product. Their effective operating range is in the area of particle size where it is impractical or uneconomical to employ screens.

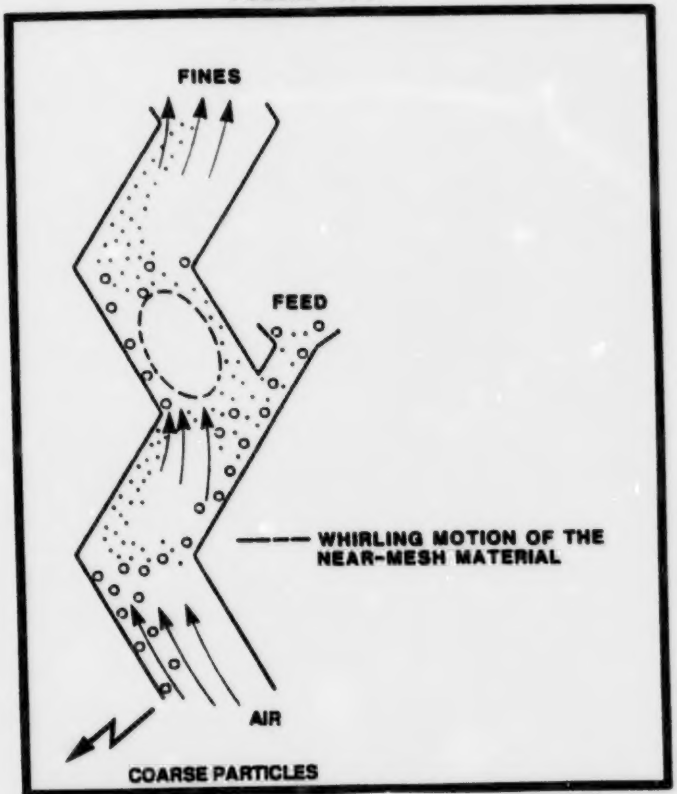
### 4.3.2 Cross Flow Classifier

In addition to gravity classifiers as described above, other types of classifiers are used for similar purposes. One type of classifier used for similar dedusting operations is the so called zig-zag classifier, which is a static type unit with no moving parts. The unit consists of a rectangular tube (in cross section) with a number of bends (Figure 4.1). Feed material enters the tube at one of these bends. Air entering at the bottom of the tube flows upwards, and depending on its velocity will carry the fine material upwards, while coarse material of greater mass continues to flow downwards toward the exit opening. The effectiveness of this type of classifier depends on the number of separating stages, the flow characteristics of material to be classified and velocity of the air stream. As with gravity separators, cross flow separators can be used effectively in dedusting operations or for separation of materials into different size classes by using several of these tubes in series each having different air flows.

Cross flow separators are characterized by high capacity, (20-200 T.P.H.) The effective operating range of cross flow type air classifiers is generally above 30 micron and typically above 100 micron. Besides the zig-zag, cross flow classifier other cross flow type air classifiers are used industrially. These are the Buell Inertial Classifier, the Ioua Rotary Drum Separator, the Alpine Ventoplex Separator, and Polysius Statopol Separator to name a few.

Bernotat, S., and Gregor, W.,(5) gave a very thorough description of the operation of cross flow classifiers in their article "Some Aspects About the Separation in a Cross-flow Air Classifier".

FIGURE 4.1



Zig-Zag Cross Flow Type Air Classifier

### 4.3.3 Centrifugal Classifiers

Centrifugal air classifiers are the most common type of classifiers in use for performing fine particle separations. The principle of operation is to generate a vortex inside the classifier by virtue of an airstream, which is introduced via a duct placed tangentially to the classifier housing. Air is supplied via an internally or externally mounted fan.

Solids to be separated are allowed to enter the vortex created in the classifier via a distributor plate or other feed mechanism. Particles will accelerate in the air stream and are subjected to centrifugal, drag, gravity and collision forces. Coarse particles, affected by centrifugal forces move in an outward direction. As they move towards the outer edge of the vortex, their peripheral velocity will decrease and gravity will overcome centrifugal and drag forces. As a result coarse particles will descend out of the air stream.

Fine particles, because of their lower mass, are affected more by the drag force of the airstream, which is greater than the centrifugal force on the particle, and are swept out of the classifying zone by the air stream leaving the classifier.

The particle size at which separation occurs is depending on the velocity of the airstream and the applied centrifugal force. If for a particle of a given size or mass the influence of centrifugal force exceeds the drag force of the air, then theoretically all particles of this mass and greater will report in the coarse fraction, while particles of lower mass will be in the fine fraction. The particle mass at which the two forces are in equilibrium is commonly referred to as the "cutpoint".

Centrifugal classifiers that depend on air from a fan to operate the centrifugal action are commonly called "free vortex" classifiers. Classifiers equipped with an internal rotor to create air flow and air velocity in the classifying zone are called "forced vortex" centrifugal classifiers. In many cases forced vortex classifiers are equipped with an additional external fan.

Free vortex type classifiers are commonly used for separations in the 30 to 100 micron range, while forced vortex classifiers are used from 50 micron to as low as 5 micron.

Forced vortex classifiers have several advantages over free vortex classifiers. The most significant is the fact that in the free vortex classifier, an increase in solids loading results in reduced particle velocity. This reduces the centrifugal force relative to the drag force exerted by the air and shifts the equilibrium between these forces to a particle with a larger mass. The cut point becomes coarser, hence product will be coarser. Therefore, variations in feed rate have an immediate effect on product quality.

In contrast, in the forced vortex classifier, air is accelerated by a mechanically driven rotor located in the classifier housing. Typically these rotors are driven by a variable speed motor. A tachometer on the motor shaft feeds a signal to a controller to maintain a constant "preset" speed. Any variation in feed rate, therefore, will not affect rotor speed or air and particle velocity in the classification zone. All that may be required is a greater power input to the rotor drive to maintain rotor speed. As a result, variations in feed rates will not affect cut point or product quality in the same way as with free vortex classifiers. At higher feed rates, classification efficiency will be reduced but product quality will be maintained. At lower feed rates classifier efficiency will improve, but the effect on product quality will be minimal. Generally, high feed rates will cause a product with a lower average particle size (due to lower classifier efficiency), while low feed rates will result in a higher average particle size due to increased classifier efficiency.

Another advantage of forced vortex classifiers is that with the classifying rotor it is possible to achieve very high air and particle acceleration resulting in high centrifugal forces, allowing separations at very low cut points. The addition of air from an external fan assists in dispersion and suspension of solids. Control over particle size of the products is by controlling the speed of the classifier rotor.

The limiting factor with respect to product fineness is the critical speed of the rotor. Rotor design and other factors are important, but in general terms the limiting factor as to the fineness of a product is a function of particle density and maximum allowable peripheral rotor speed, since separation is based on centrifugal force and particle mass. Finer products require increased centrifugal force which is generated by the speed of the classifying rotor.

In general, lower cut points and therefore finer products can be achieved with classifiers with smaller rotors, depending on other geometrical factors such as the relationship between diameter of the classifier housing and rotor diameter. Smaller rotors produce classifying zones or vortexes of smaller diameter with higher possible particle velocity compared to larger rotors. This is analogous to hydrocyclones in which product fineness is a function of cyclone diameter, pressure and pulp density. A smaller rotor also dictates overall classifier dimension, particularly the diameter of the section where the separation is made. A physical reduction in classifier and rotor size also reduces the maximum effective feed rate to the classifier, but as noted will also allow finer cut points.

In general, all other factors being equal, classification efficiency increases at higher cut points and decreases at lower cut points. In "state of the art" superfine classifiers, products with a top size of five (5) micron have been achieved but at low yield, relative to theoretical possible yields.

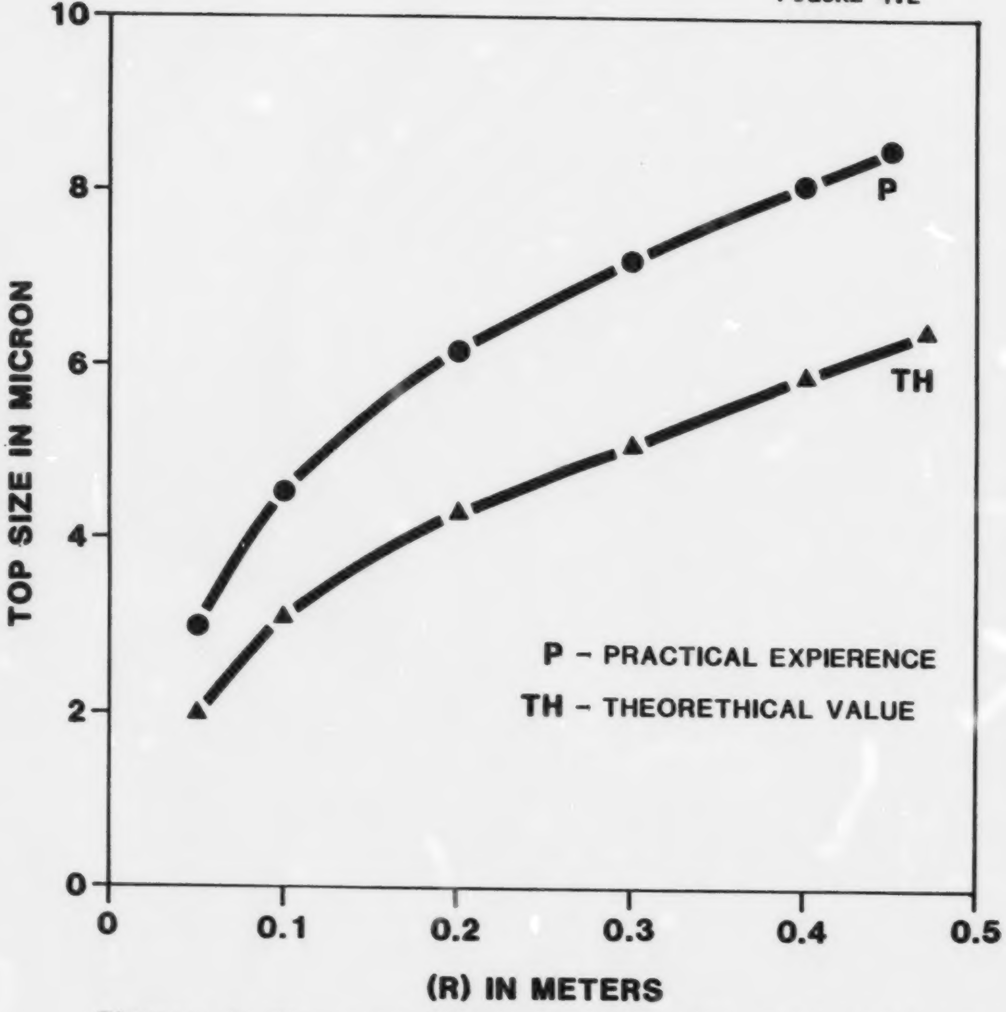
The relationship between cut point or product fineness is shown in Figure 4.2.

De Silva, S.R.(1) gives an excellent theoretical overview of air classification in which he discusses in detail the theoretical aspects of air classification.

Alpine American(15) conducts seminars on air classification and has prepared an excellent seminar course book that discussed the practical and theoretical aspects of air classifications.

## FINENESS IN MICRON RELATIVE TO THE RADIUS (R) OF CLASSIFYING ZONE

FIGURE 4.2



Fineness in Micron relative to the Radius(R) of Classifying Zone.

## 4.4 How to Evaluate Air Classification Equipment

Technical evaluation of air classification equipment must be based on the specific requirements of products to be produced, capacity required, control flexibility and classifier efficiency.

Other aspects of importance are: engineering integrity, ease of maintenance, physical size, requirements for auxiliary equipment such as fans, feed mechanism, method of product and reject discharge and dust collection.

For the purpose of this study, only technical evaluations, i.e. ability to produce the desired product(s), classifier efficiency and process control will be considered.

Based on product and capacity requirements, it is possible to identify various makes or types of classifiers designed to fulfill these specific requirements, followed by actual classification tests on a test sample.

The following criteria should be considered in a test program:

- o Sample to be tested must be representative of the output from the grinding equipment.
- o Material must be dry and packaged so no water can enter.
- o The size distribution of the feed sample must be known as determined by a method of particle size analysis which is satisfactory.

- o Transportation of the sample may cause settling, packing, etc., which results in the sample being in a different physical condition than when it was collected. It is advisable, if possible, to aerate the sample prior to testing.

- o Air temperature, elevation and humidity have an effect on air classification. The test equipment should be operated for the required time (without feed) to reach a stable operating temperature. Warm air is less dense and will affect performance

### 4.4.1 Test Program

The classifier manufacturer will have a good knowledge of the operational characteristic of his equipment, and is able to estimate the various operational parameters that will result in a good approximation of the products required. These operating variables are likely to include air volume, i.e. fan speed, rotor speed, and feed rate.

In general, it is advisable to first run a series of tests at a constant feed rate and air flow and over a range of rotor speeds. By plotting achieved product quality against rotor speed, it is possible to select the appropriate rotor speed. It is suggested to start at a relatively low feed rate

Once rotor speed is established, additional tests using the same feed rate, selected rotor speed and a range of air volumes (or velocity) should be conducted. This will allow evaluation of this variable on product quality and yield.

Following this, assuming satisfactory results are achieved, the effect of feed rate on product quality and yield can be established by conducting tests at optimum rotor speed, air flows and a range of feed rates.

The steps as outlined above will give a good indication of classifier performance relative to efficiency of separation, optimum feed rate, product quality, and power requirements.

Comparative testing of several classifiers while not mandatory, is suggested so active comparisons can be made. Any decision should be made on the basis of technical and economic factors.

## 4.5 State of the Art in Air Classification

There are a number of methods or approaches to air classification as practiced in industrial application of air classification technology.

Following are examples of different methods of using air classification technology to achieve various objectives with respect to product quality, separating efficiency and overall process efficiency.

Utilization of air classification as a process can be classified into two main areas. These are:

- Air classification as part of a closed circuit grinding classification system with the classifier coarse fraction returning to the mill for further grinding.
- Dedicated air classification, i.e. not coupled with a grinding circuit, producing one or more products simultaneously, from a feed material produced by grinding or other processes.

Each of these two can be expanded into several process variables using one or more classifiers in the process.

### 4.5.1 Closed Circuit Grinding Classification

Several approaches to closed circuit grinding-air classification can be considered. In each case, the approach taken is predicated by the desire to optimize the efficiency of the grinding and air classification circuit with respect to system productivity, energy consumption, and product quality.

### 4.5.2 Two Stage Air Classification

Two stage air classification can be employed if the installed classifier in use is of the low efficiency type, resulting in significant potential product being discharged with the classifier reject (coarse) fraction.

By installing a second, preferably high efficiency classifier to reclassify rejects from the first classifier, significant additional amounts of product can be extracted. In essence, two stage classification minimizes the return of fines (of product size) to the mill. Excessive fines can cause problems in grinding mills by changing the flow characteristics of the material in the mill, result in overgrinding or cause agglomeration and/or coating of mill walls and grinding media.

Typically, if a high efficiency classifier is used in the second stage, combined products from the two classifiers tend to have a steeper size distribution compared with products produced by single stage classification.

Another approach that has found application is to produce two or more products, either by operating classifiers in series, each producing a product with a different size distribution, or with two (or more) classifiers in parallel.

In the series mode, the first classifier produces the finest product, while the second classifier extracts a coarser product from the rejects of the first classifier.

The objective is to extract the maximum amount of product from the mill discharge, returning the minimum amount of "potential" product to the mill.

In the parallel mode, the feed is split, and fed to each classifier separately. Either two different, or two identical products can be produced in this manner. This approach finds application in situations where it is desirable to produce products of 20 microns or finer top size. Mill capacity may be such that the total flow of material to be classified exceeds the effective handling capacity of the classifier employed. In such cases, it is necessary to install a second identical classifier to twin the system. Systems of this type with as many as six separate classifiers operating in closed circuit with a grinding mill are used in the production of very fine filler products.

A similar approach can be taken using a "multiple stage" series classification. This method is used when multiple products are required. In this system, one or more grinding mills are providing feed for a number of classifiers operating in series. In this case, the classifiers are deliberately operated inefficiently by overloading the classifiers. The first classifier produces the finest product required, but at low classifying efficiency. This results in large volumes of potential product in the classifier rejects. These rejects are then re-classified in a second classifier, operated so as to make a coarser product.

This may be repeated several times, each stage extracting a coarser product. Reject (from which all possible product has been stripped) is returned to the mill for regrinding.

Products produced in this manner, particularly those produced in the last stages tend to have steep size distributions. This system while it can be effective has several drawbacks. In the first instance, mechanical or electrical failure of one of the units in the series may result in a complete shutdown of the system. The second drawback is that the products produced may not be in balance with market requirements. If one product is either in short or oversupply, it is difficult to maintain system balance.

### 4.5.3 Dedicated Air Classification Circuits

In some instances it is advantageous to conduct air classification as a dedicated process, as separate from primary separation in closed circuit grinding-classification processes. This system finds application in the so-called "two product" approach. In this system, product produced by a "closed circuit" grinding and classification unit used as feed for one or more "dedicated" air classifiers operated independently from primary closed circuit grinding systems.

To give an example, a primary grinding and classification circuit is operated in such a manner as to produce a product with the required "top size", i.e. 99% passing 325 mesh (45 micron) screen.

Product as produced is stored in a bin from where it is fed via a suitable feeding mechanism to one or more high efficiency classifiers. These classifiers operated at optimum feed rate, air flow and rotor speed produce fine, 10, 15 or 20 micron top size products, and/or a specific average or median particle size. Coarse fraction from the classifier which has a controlled top size, (produced in the primary system) becomes the second product. In this method of operation, both fines and rejects from the classifier are products. If two classifiers are used in parallel, it is possible to produce as many as four products.

### 4.5.4 Multi-Stage Dedicated Air Classification

Series or staged classification is a concept that has merit in a dedicated classification circuit. As in closed circuit staged classification, a number of air classifiers are operated in series. Rejects from the first stage is reclassified in the second stage and so forth, with each classifier producing a progressively coarser product. In the final classification stage both fines and rejects can be product or the coarse fraction becomes mill feed. The system depends on providing feed material with controlled top size. To make the system function it is necessary to deliberately overfeed the first classifier. By controlling air flow and rotor speed the desirable product will be produced at low classifier efficiency and relatively low product output. This system of operation is often referred to as "fines milking". It is used to advantage in production of a wide range of products, usually mineral fillers.

Another factor not to be overlooked is that it is essential (in order to achieve efficient air classification) that feed to the classifier is fully dispersed, i.e. all particles are separated from each other. In closed circuit systems consisting of a mill and single classifier, the classifier has only one opportunity to disperse the feed. If it is not completely dispersed, agglomerated particles will appear with the reject fraction, despite the fact they consist of fine particles. In multi-stage classification, material is dispersed several times, minimizing the chances of fines (in the form of agglomerates) returning to the mill.

It is generally accepted that it is advantageous, if practical, to minimize the return of "product" sized fines to the mill. The staged classifications approach, producing several products with either no rejects at all or only small amounts of relatively coarse sized material, can, despite being inefficient from a classification viewpoint, be the most efficient, if grinding efficiency is taken into the equation.

The staged approach to air classification is practical only in operations with a multi-product range, as is usually the case in production of mineral filler products.

The cement industry usually adheres to the "closed circuit" grinding and classification approach. However, there are instances where Two Stage Classification is used. Some examples are as described by Eronin, H.C.(5) in his article How Two Stage Classification affects cement grinding at Ciment Lafarge's plant, Limay, France, and in Heiskanen K.C.(6)'s article Two Stage Air Classification and why?

## 5.0 NEW TYPES OF AIR CLASSIFIERS

The development of air classification equipment is a continuous process. New types, models and modifications of existing classifiers are being introduced continuously.

In all cases, newly introduced equipment is designed on the basis of a better understanding of the principles of aerodymanics, particle behaviour in air or gas streams and the interactivity of air flow, particle velocities and centrifugal forces.

This, in general, has resulted in equipment with significantly better classification efficiency, improved control of the classifiation process, reduction in physical size of classifiers and higher capacities.

Constant demands by consuming industries for finer and more closely controlled particle size distributions are a major part of the driving force behind the development of high efficiency air classifiers.

The second, and equally important factor, is the realization that it is an essential component in achieving better energy utilization in continous comminution processes because of improved separating efficiency. By reducing the amount of potential product in the oversize from a classifier being returned to the grinding mill, not only results in improved productivity, it also reduces overgrinding.

The basic objective in the continuous grinding and classification process is to remove the bulk of the desired particle size during the classification process and prevent "PRODUCT SIZE" material from being returned to the grinding mill.

## 5.1 CLASSIFICATION EQUIPMENT FOR ULTRA-FINE SEPARATION

Ultra-fine particle separation is an essential process in the manufacturing of fine filler products. Due to increased use of fine mineral fillers such as calcium carbonates, talcs, nepheline synenite, pigments and metallic powders, many industrial filler consumers challenged the processing industries to produce ever finer and closer controlled filler products.

Demands by industry for very fine products with controlled particle size distribution, surface area, and median particle size, presented a challenge to mineral producers and manufacturers of air classification equipment.

Classifier manufacturers worldwide responded to this challenge by developing high efficiency air classification equipment capable of producing these very fine products efficiently.

As is shown in section 4.3.3 the ability of a classifier to achieve cut points at low micron sizes is a function of classifier geometry. Finer products, in general, can be produced in units of smaller size. To produce fine products requires that high centrifugal forces be generated by the separating rotor. To develop these necessary contrifugal forces requires high rotor speeds, to overcome the drag forces of the particle laden air or gas stream.

Of equal importance, is the ability of the classifier to disperse and suspend material to be classified in the airstream.

For these reasons, classifiers capable of making separations at cut points below ten (10) microns, tend to be small in size and of low capacity. The same size classifier can also produce coarser products, at increased feed rates and coarser cut points.

Of extreme importance, when evaluating a high efficiency classifier, is to determine what products are to be produced.

It is essential that the classifier can efficiently produce the finest product required. Establishing its capacity is, to some extent, dependant on the fineness of the feed to the classifier. Several samples of feed fineness should be tested to find the most effective combination of capacity and efficiency.

A number of high efficiency air classifiers are available on the North American market. Most manufacturers produce a number of models in order to facilitate a broad range of individual requirements of product fineness and capacity.

Following is a list of commerically available classifiers in North America. The list is not intended as a endorsement of these classifiers, nor is it claimed to be complete.

## HIGH EFFICIENCY AIR CLASSIFICATION EQUIPMENT AVAILABLE IN NORTH AMERICA

### ALPINE AMERICAN - TURBOPLEX ULTRA-FINE CLASSIFIERS

Alpine is a German based company with manufacturing and sales facilities in Natick, Mass. The company produces a wide range of air classification equipment including several types and models of high efficiency air classifiers.

The trade name for Alpine's ultra-fine classifiers is Turboplex and they are available in eight models of different size and configuration. The Turboplex classifier is unique, in that, it is the only classifier where the classifying rotor is in a horizontal rather than the typical vertical position. This classifier is also unique in that the models come with either one, three, four or six rotors each driven separately. All rotors produce the same product with material exiting through a common fixed discharge port.

The smaller units, models 100 and 200, have lower cut points and feed handling capabilities. The larger units, 315, 500, 700, and 1000 models, have higher cut points, but significantly higher feed rate capacities.

Alpine American is now owned by the Hosakawa Company of Japan. Sales are handled from Summit, New Jersey by the Mikropul Corporation. This same organization also markets "MIKRON SEPARATORS".

## BRITISH REMA-AEROSPLIT CLASSIFIERS

The Rema-Aerosplit air classifier is of British design, available in the U.S. through Prater Industries Inc. of Chicago and in Canada through Firing Industries of St. Catharines, Ontario.

Five model sizes are marketed with the designations MAC-1 to MAC-5. Each of these units is designed for a range of air separation capabilities, with the smaller units achieving finer cut points at lower capacities. The larger units logically, provide coarser cut point ranges and have much greater thru-put capacities.

## C.E. RAYMOND - JET STREAM CLASSIFIERS

C.E. Raymond, a division of Combustion Engineering Inc., of Chicago, markets three standard models of the Jet-Stream and two optional larger units. The standard models are the JS-4.5, JS-25 and the JS-35, the optional units are designated as the JS-80 and JS-180. The product designation is based on the physical dimension of the unit and the actual model designation being derived from the airflow (CFM) characteristics.

For example, nominal feed rates, to produce a limestone product with a top particle size of ten (10) microns with a two (2) micron average, ranges from 200 lb/hr for the JS-4.5, to 8300 lb/hr for the larger JS-180 unit.

## GEORGIA MARBLE - AIR SIFTER

The Georgia Marble Company, a division of the Jim Walter Corporation, of Tate, Georgia, manufactures two models of air sifters, the G-24 and G-40. These units are used for production of filler products with a top size of 10 microns, but can also make much coarser products.

The smaller G-24, has a feed capacity of 300 to 3000 lb/hr depending on the cut point desired and fineness of the feed. The G-40 can produce the same products as the G-24, but at feed rates of 3000 to 30000 lb/hr.

Georgia Marble is a large producer of calcium carbonate filler products operating several plants in the United States. The company makes extensive use of their own air classification equipment. In this regard, they formed the air sifter division to develop, manufacture and market their own classifiers.

## PROGRESSIVE INDUSTRIES, INC. - MICROSIZER

Progressive Industries Inc. of Sylacagua, Alabama is the producer of a range of air classifiers. Four basic Microsizer units are marketed under the designation MS-5, MS-20, MS-50 and MS-100, with other models under development.

The MS-5 and MS-20 are designed to produce superfine filler products with a top particle size of less than 10 microns, but capable of making cuts at 100 microns, at much higher feed rates.

Feed rates for producing a 10 micron product depends on the fineness of the feed and product required. Feed rates range from 300 to 5000 lb/hr for the MS-5 and from 3000 to 60,000 lb/hr for the MS-20 depending on feed size and cut point required. The MS-5 is available in a pilot plant configuration for "on site" testing at customer plants and is equipped with variable speed drives on both rotor and fan to provide a extensive range of test possibilities.

The larger MS-50 and MS-100 units are designed for classification at coarser cut points and higher feed rate capacities.

The MS-5 and MS-20 are used extensively in industry for a wide range of applications to produce mineral fillers, pigments and metal powders.

## STURTEVANT - SUPERFINE AIR SEPARATOR

The Sturtevant Mill Company manufactures a wide range of air classification equipment. The Superfine series is produced in three models of 20", 36" and 72" diameter. These units have the capability of making products with a top size of 15 microns or less. Feed rates range from 300 to 10,000 lb/hr depending on feed sizes and cut point required.

## Conclusion

The foregoing classifiers are all in the family of superfine high efficiency air classifiers. Selection of a air classifier must be based on individual needs relative to production and capacity requirements. Equipment testing is essential and needs to be conducted on the actual material for which the classifier is to be used. Comparative testing will determine which type or size of classifier best fulfills the specific needs.

There is a broad range of other high efficiency air classifiers available, but lack the capacity of producing superfine products. These classifiers are effective in the 30 to 100 micron range and are often used for pre-classification or are operated in closed circuit with various types of grinding equipment.

Most of the classifiers described as superfine classifiers are capable of producing coarser products, but may not always have the high feed rate capacity. In general, superfine classifiers are designed to operate at a high efficiency mode and produce very fine products.

## 5.2 CLASSIFICATION EQUIPMENT FOR CEMENT CLASSIFICATION

The cement industry is a large consumer of energy to produce clinker and in grinding clinker to produce cement of the desired particle size and blaine surface area.

In 1983, Canada produced 7.52 million tons of cement with a average energy consumption of 76.0 kWh/ton for grinding clinker to the specification of type 10 cement.

Cement plants normally operate at very high tonnage rates. Their grinding mills are big, usually of the ball or tube mill type, operating in closed circuit with large mechanical type air classifiers.

Many of these grinding units, with conventional mechanical air classification systems, have been in place for a number of years, dating from the days when energy cost was not a major concern. With the escalation of energy cost in the 1970's, cement producers began to review ways and means to conserve energy. One area targeted was to improve energy utilization in the grinding circuit. Besides, reducing energy costs, cement producers had to also respond to consumer demands for finer and closer controlled cement products. In many cases, this resulted in taxing the capability of conventional mechanical air classifiation equipment to produce cements efficiently.

It was commonplace to find, that either due to overloading of classifiers or because classifiers operated under more demanding requirements, relative to product quality, separation efficiency was greatly reduced. Rejects from air classifiers contained significant amounts of potential product which was being returned to the grinding mills. This affected performance of grinding circuits, causing overgrinding.

It is an established fact that excessive fines in the mill charge, affects the transportation characteristics of the material in the mill. It also leads to the formation of agglomerates.

Manufacturers of air classification equipment recognized that efficient air classification is an important feature in increasing overall efficiency and productivity of a cement grinding facility. As a result, manufacturers of classification equipment focused their research on improving cement classification. This led to new and more efficient equipment. As a result, a new generation of high efficiency air classifiers are being marketed specifically targeted for use in cement manufacturing.

These new types of classifiers represent a significant improvement in design, controllability and reduction in equipment size. The most significant effect has been in the increased level of classifier efficiency, the positive effect on circuit productivity and the reduction in energy consumption. Specific examples are provided in section 8.0.

In most cases, these "state of the art" air classifiers are completely new designs. Other manufacturers have taken the approach of retrofitting existing classifiers, by adding newly designed internals, to obtain the desired classification efficiency. This approach has the avantage of minimizing installation time and productivity losses due to down time. The particular method chosen is a matter of choice for each company, but retrofitting is of particular interest in existing plants.

New plants or expansion programs will benefit most by installing totally new units. Primarily, because of the reduced space requirements of these new units, which are much smaller in physical size.

One possible approach, to take advantage of these new air classifiers which have not received as much attention as they deserve, is the use of multi-stage classification.

This concept uses existing conventional air classification equipment as the first stage of primary classification, followed in series by a "state-of-the-art" high efficiency classifier to reclassify rejects from the first stage.

This approach can be effective, if adequate space is available to install the second stage classifier in the circuit.

The use and validity of the multi-stage approach is demonstrated in the testwork described in section 6.0.

## 5.2 CLASSIFICATION EQUIPMENT FOR CEMENT

The following is a listing of manufacturers marketing high efficiency air classifiers for use in cement and other appropriate air classification applications.

The list consists of air classifiers most commonly used by the cement industry. Listing of any particular classifier is not to be considered an endorsement. Other classifiers, not listed, may be of equal quality.

### 5.2.1 C.E. RAYMOND - DIVISION OF COMBUSTION ENGINEERING

This company produces the Raymond high efficiency mechanical air separator, which is available in six sizes designated as Models 12, 14, 16, 18, 21 and 24. These units have the following rate range:

| MODEL | FEED RANGE STPH | CLASSIFIER HOUSING DIAMETER | HP |
|---|---|---|---|
| 12 | 107 - 132 | 9' 4" | 200 |
| 14 | 132 - 175 | 10' 9" | 275 |
| 16 | 175 - 234 | 12' 4" | 350 |
| 18 | 234 - 293 | 14' 0" | 450 |
| 21 | 293 - 410 | 16' 0" | 650 |
| 24 | 410 - 527 | 18' 8" | 900 |

Most of the horse power requirement is for the fan providing air for classification and cooling. The air is a "once thru" system, i.e. air is not circulated and leaves the classifier system after separation of the product from the air in an appropriate collector, usually of the bag collector type

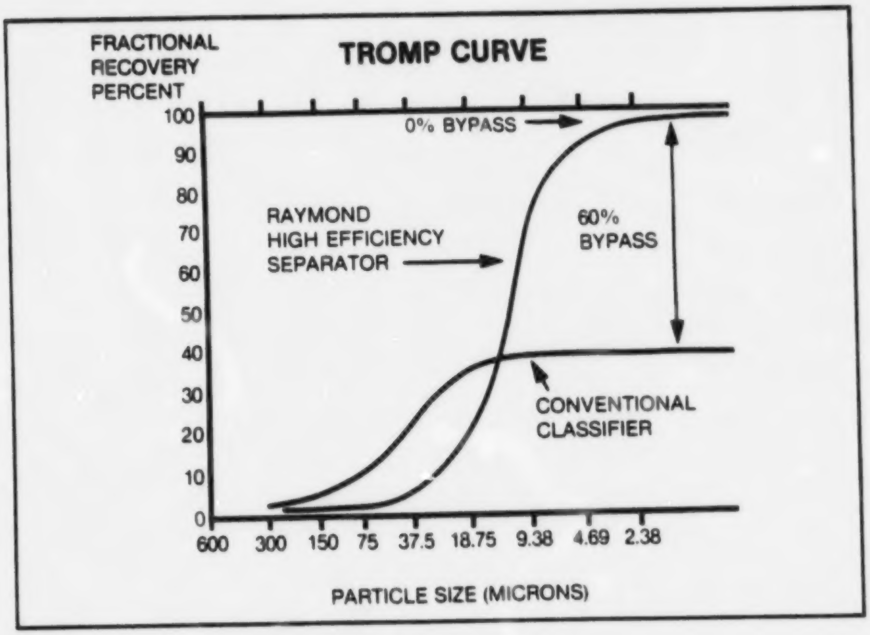
This separator is described by Dunn, M.R.(C10) in his paper entitled "Development of the Raymond High Efficiency Mechanical Air Separator". The same author, in 1985, published a paper on a method for analysing the performance of a mechanical air separator.

The Raymond high efficiency air separator is available as a complete unit or as a retro-fit package for upgrading older conventional Raymond air separators.

C.E. Raymond Bulletin No. 864, provides a table outlining the nominal cement production rate for cement with Blaine surface areas of 3000-4000 cm$^2$/gram at various levels of mill circulating loads.

The same bulletin also compares the tromp curves of the Raymond high efficiency separator with their conventional classifier. This is shown in figure 5.2.1-1 below.

FIGURE 5.2.1-1



Source C.E. Raymond Bulletin No. 864.

As indicated by these figures, the high efficiency separator has a much improved classification efficiency. No data was presented to indicate, if the cement feed to the classifier was identical and if the feed rates at which comparison was made, were similar.

### 5.2.2 FULLER - O-SEPA HIGH PERFORMANCE AIR SEPARATOR

The O-Sepa air classifier is a development of the Onada Cement Company, Onada Engineering and Consulting Co. Ltd., Tokyo, Japan.

The O-Sepa is marketed in Canada by the Fuller Traylor Company. Fuller maintains testing facilities in Bethlehem, Pennsylvania.

A complete range of air classifiers of this design, are available for classification of cement or other materials, such as limestone, slag, coal etc.

A total of nine production size units, plus a small pilot plant unit, are available. This range of separators covers a feed capacity from a low of 75 T.P.H. for the smallest production unit to as high as 1200 T.P.H. for the largest.

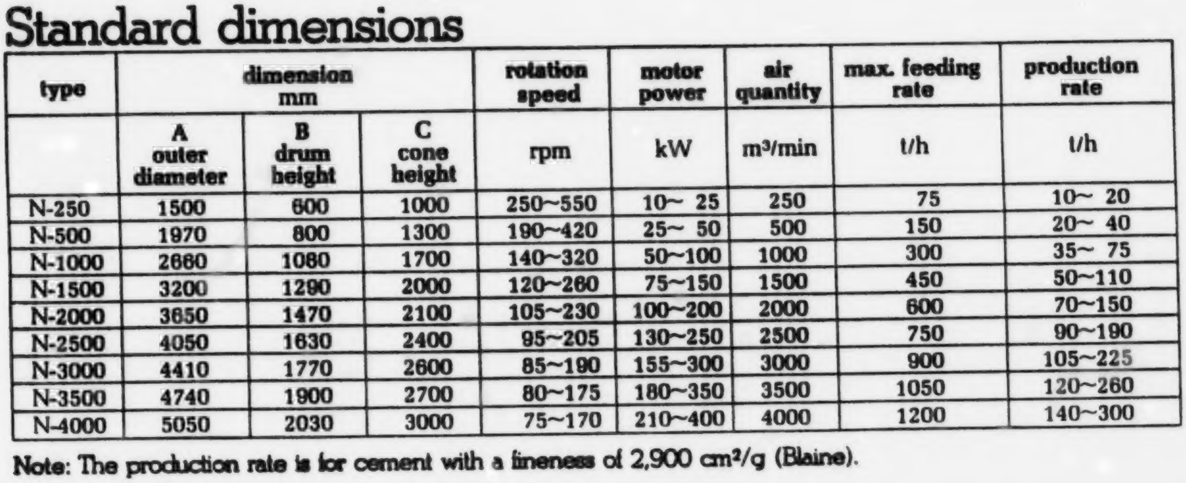
Many O-Sepa high efficiency air classifiers have been installed in cement plants worldwide.

This classifier was described in detail in a paper by Onuma, E. and Furawaka, T.(C-3) published in World Cement in Jan./Feb. of 1984, under the title "O-Sepa a new High-Performance Air Classifier".

Section 6.0 of this study outlines the results of pilot plant testing with the N-20, pilot plant unit, using both, a cement mill discharge and rejected material (oversize) from a conventional air classifier.

Table 5.2.2-1 gives details on the various sized units and their capacities. Figure 5.2.2-2 shows a schematic diagram of the O-Sepa classifier. Figure 5.2.2-3 shows comparative tromp curves for two (2) conventional separators and the O-Sepa high efficiency air separator.

TABLE 5.2.2-1



## Standard dimensions

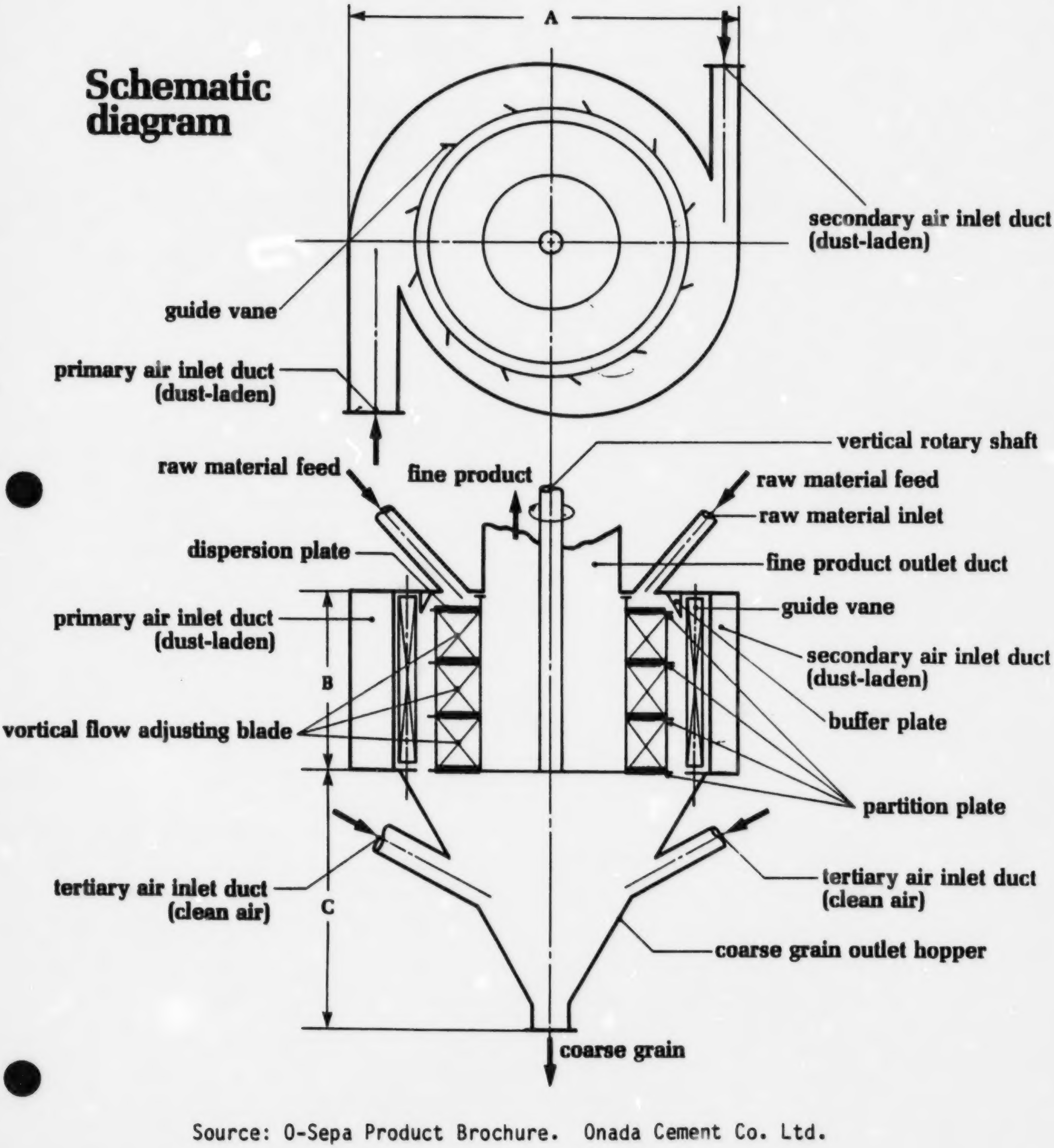
| type | dimension mm | | | rotation speed | motor power | air quantity | max. feeding rate | production rate |
|---|---|---|---|---|---|---|---|---|
| | A outer diameter | B drum height | C cone height | rpm | kW | m³/min | t/h | t/h |
| N-250 | 1500 | 600 | 1000 | 250~550 | 10~ 25 | 250 | 75 | 10~ 20 |
| N-500 | 1970 | 800 | 1300 | 190~420 | 25~ 50 | 500 | 150 | 20~ 40 |
| N-1000 | 2660 | 1080 | 1700 | 140~320 | 50~100 | 1000 | 300 | 35~ 75 |
| N-1500 | 3200 | 1290 | 2000 | 120~260 | 75~150 | 1500 | 450 | 50~110 |
| N-2000 | 3650 | 1470 | 2100 | 105~230 | 100~200 | 2000 | 600 | 70~150 |
| N-2500 | 4050 | 1630 | 2400 | 95~205 | 130~250 | 2500 | 750 | 90~190 |
| N-3000 | 4410 | 1770 | 2600 | 85~190 | 155~300 | 3000 | 900 | 105~225 |
| N-3500 | 4740 | 1900 | 2700 | 80~175 | 180~350 | 3500 | 1050 | 120~260 |
| N-4000 | 5050 | 2030 | 3000 | 75~170 | 210~400 | 4000 | 1200 | 140~300 |

**Note:** The production rate is for cement with a fineness of 2,900 cm²/g (Blaine).

Source: O-Sepa product brochure. Onada Cement Co. Ltd.

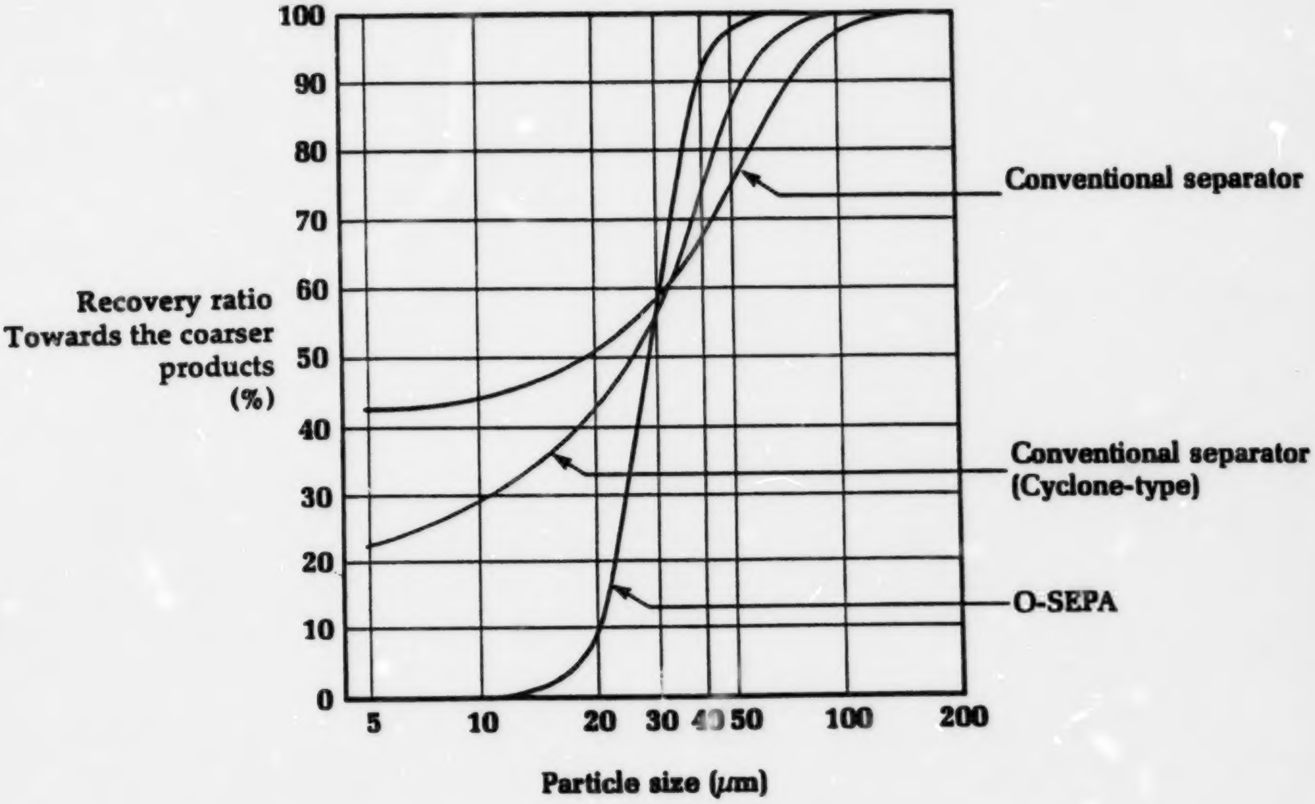
SCHEMATIC DIAGRAM O-SEPA HIGH PERFORMANCE AIR SEPARATOR

FIGURE 5.2.2-2


Schematic diagram
A
secondary air inlet duct (dust-laden)
guide vane
primary air inlet duct (dust-laden)
vertical rotary shaft
raw material feed
fine product
raw material feed
raw material inlet
dispersion plate
fine product outlet duct
primary air inlet duct (dust-laden)
guide vane
secondary air inlet duct (dust-laden)
B
buffer plate
vortical flow adjusting blade
partition plate
tertiary air inlet duct (clean air)
C
tertiary air inlet duct (clean air)
coarse grain outlet hopper
coarse grain

Source: O-Sepa Product Brochure. Onada Cement Co. Ltd.

FIGURE 5.2.2-3 Comparison of Tromp curves for two types of conventional air separators and O-Sepa High Efficiency Air Separator.



Source: O-Sepa Product Brochure. Onada Cement Co. Ltd.

The tromp curve, for the O-Sepa air separator, shows excellent classification efficiency compared to conventional separators. The data does not indicate if this comparison is based on similar operating conditions, cement feed quality and feed rates.

In March 1985, the Fuller Company published an article by Brugan, M.J., entitled "O-Sepa Application and Results". This industrial publication is available from the Fuller Company.

### 5.2.3 LAROX EC CENTRIFUGAL CLASSIFIER

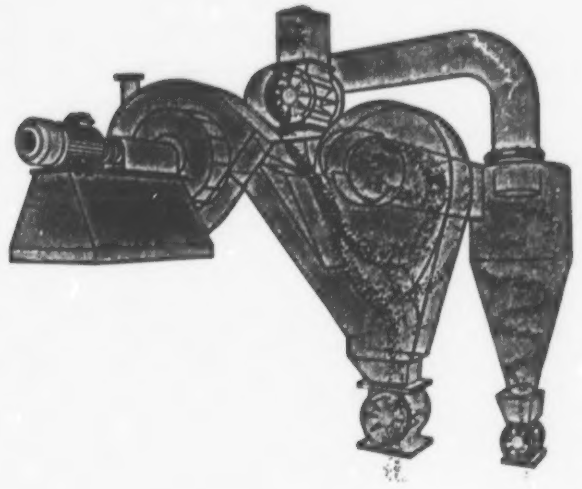
The Larox EC centrifugal air separator is a completely different type of air classifier. This classifier has no internal moving parts and depends on centrifugal air flow and gravity as its separating principle. This classifier was developed in Finland by Professor R.T. Kukki of the Finnish Technical Research Centre.

Air to disperse the feed and provide the required centrifugal force is supplied by a medium or high pressure blower located outside of the classifier housing. Feed material entrained in the air flow achieves a centrifugal motion in the housing. The coarse fraction, contained in the feed material is directed outwards by centrifugal force and drops out of the air stream while finer particles continue to be airborne and are discharged via a central outlet in the classifier housing to a cyclone. Product is separated from the air in the cyclone and air is returned from the cyclone, operating in closed circuit with the blower, to the primary and secondary dispersion stages.

Figure 5.2.3-1 shows the Larox EC Centrifugal Air Separator.

FIGURE 5.2.3-1

## LAROX TYPE EC CENTRIFUGAL SEPARATOR



Source: Larox product bulletin #116 - 1982

The Larox EC Centrifugal Air Separator is avalable in a range of sizes and capacity as shown in Table 5.2.3-2.

TABLE 5.2.3-2

**Reference capacity data for cement** - Larox EC Classifier

| | Average production, t/h | |
|---|---|---|
| **Unit size** | **Standard cement**** | **Rapid cement***** |
| EC 3* | 3 | 1.5 |
| EC 6* | 6 | 4 |
| EC 10 | 10 | 7 |
| EC 20 | 20 | 13 |
| EC 30 | 30 | 20 |
| EC 60 | 60 | 40 |
| EC 90 | 90 | 60 |

* Suitable for laboratories, pilot plants and small-scale industrial use.

** Standard cement: specific surface area 300...350 m²/kg.

*** Rapid cement: specific surface area about 450 m²/kg.
For dimensions see back cover

The Larox Company is a proponent of two stage classification. This approach is described in two articles:

The first article by Hukki, R.T., Karhunen, J., and Lindsberg, R.(C-9) details their research on the two stage classification of cement.

The second article by Herronen, H.(C-5) details the effect of two stage air classification on cement grinding and productivity, at the Ciment Lafarge plant, Limay, France.

The Larox EC Type centrifugal air separator is a totally different approach to air classification compared to either conventional or new type of high efficiency air classifiers.

### 5.2.4 STURTEVANT INC. SD HIGH EFFICIENCY AIR CLASSIFIER

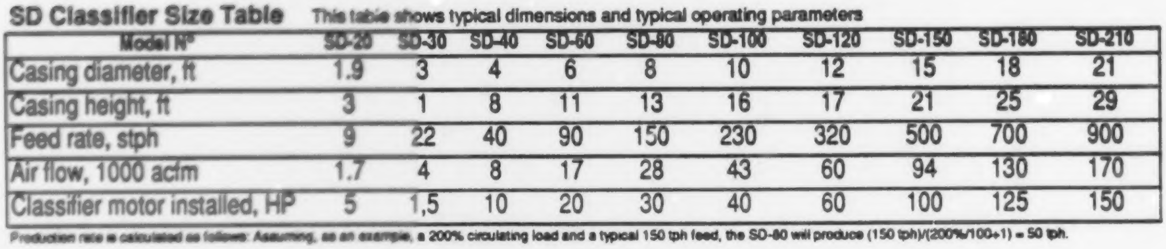
The Sturtevant Company has for many years provided a wide range of air classifiers for cement and other mineral classification. Their newest type, the SD (side draft) high efficiency classifier, was developed for use in the cement industry. As with most of the "state of the art" cement classifiers, these units provide high efficiency separation in units of much smaller physical size compared to conventional separators. This, plus the ability to achieve better and more controlled classification, are the major benefits of high efficiency air classifiers.

Sturtevant, produces the SD classifier in a range of ten (10) models, as shown in table 5.2.4-1. Of these, only the larger units are of a capacity typically encountered in cement production.

The SD classifier can be operated in several different configurations. These are: (a) an open system with dust collectors operating with 100% ambient air; (b) an open system with a dust collector, mill and ambient air; and (c) an open system with cyclones and additional venting via dust collectors to provide additional cooling.

Figure 5.2.4-2 shows Tromp Curves obtained at three levels of product fineness.

TABLE 5.2.4-1



**SD Classifier Size Table** This table shows typical dimensions and typical operating parameters

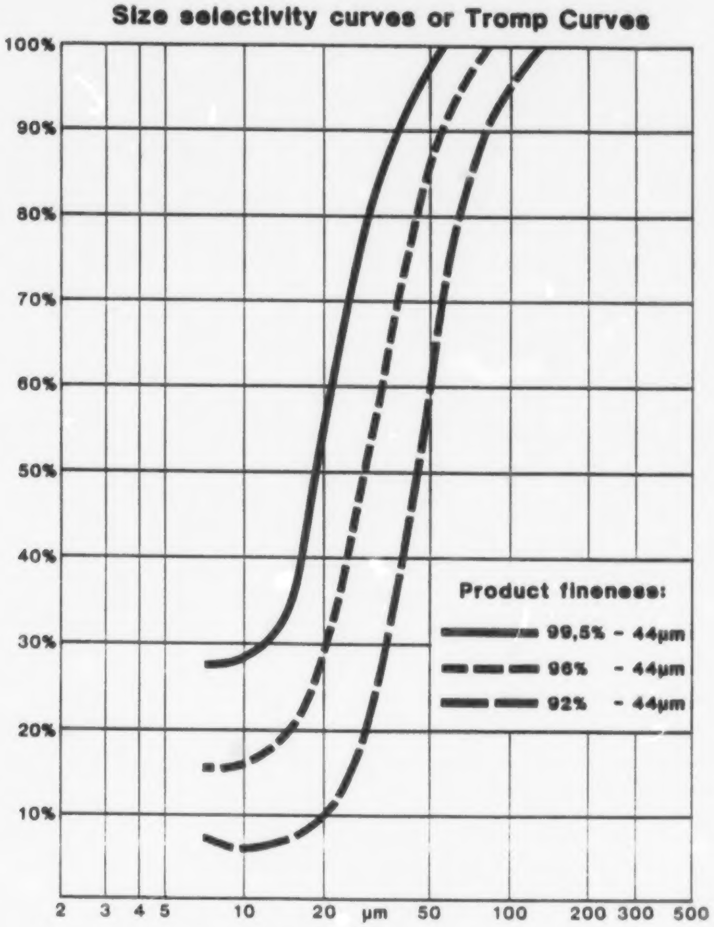
| Model N° | SD-20 | SD-30 | SD-40 | SD-60 | SD-80 | SD-100 | SD-120 | SD-150 | SD-180 | SD-210 |
|---|---|---|---|---|---|---|---|---|---|---|
| Casing diameter, ft | 1.9 | 3 | 4 | 6 | 8 | 10 | 12 | 15 | 18 | 21 |
| Casing height, ft | 3 | 1 | 8 | 11 | 13 | 16 | 17 | 21 | 25 | 29 |
| Feed rate, stph | 9 | 22 | 40 | 90 | 150 | 230 | 320 | 500 | 700 | 900 |
| Air flow, 1000 acfm | 1.7 | 4 | 8 | 17 | 28 | 43 | 60 | 94 | 130 | 170 |
| Classifier motor installed, HP | 5 | 1,5 | 10 | 20 | 30 | 40 | 60 | 100 | 125 | 150 |

Production rate is calculated as follows: Assuming, as an example, a 200% circulating load and a typical 150 tph feed, the SD-80 will produce (150 tph)/(200%/100+1) = 50 tph.

Source: Sturtevant Inc. Product Brochure - SD High Efficiency Air Classifier - 1985.

## FIGURE 5.2.4-2

Tromp curves for Sturtevant SD High Efficiency Air Classifiers at three levels of product fineness.



Size selectivity is the mass percentage of the feed particles of a given size that enter the coarse product. The minimum of the size selectivity curve is called apparent "by pass".

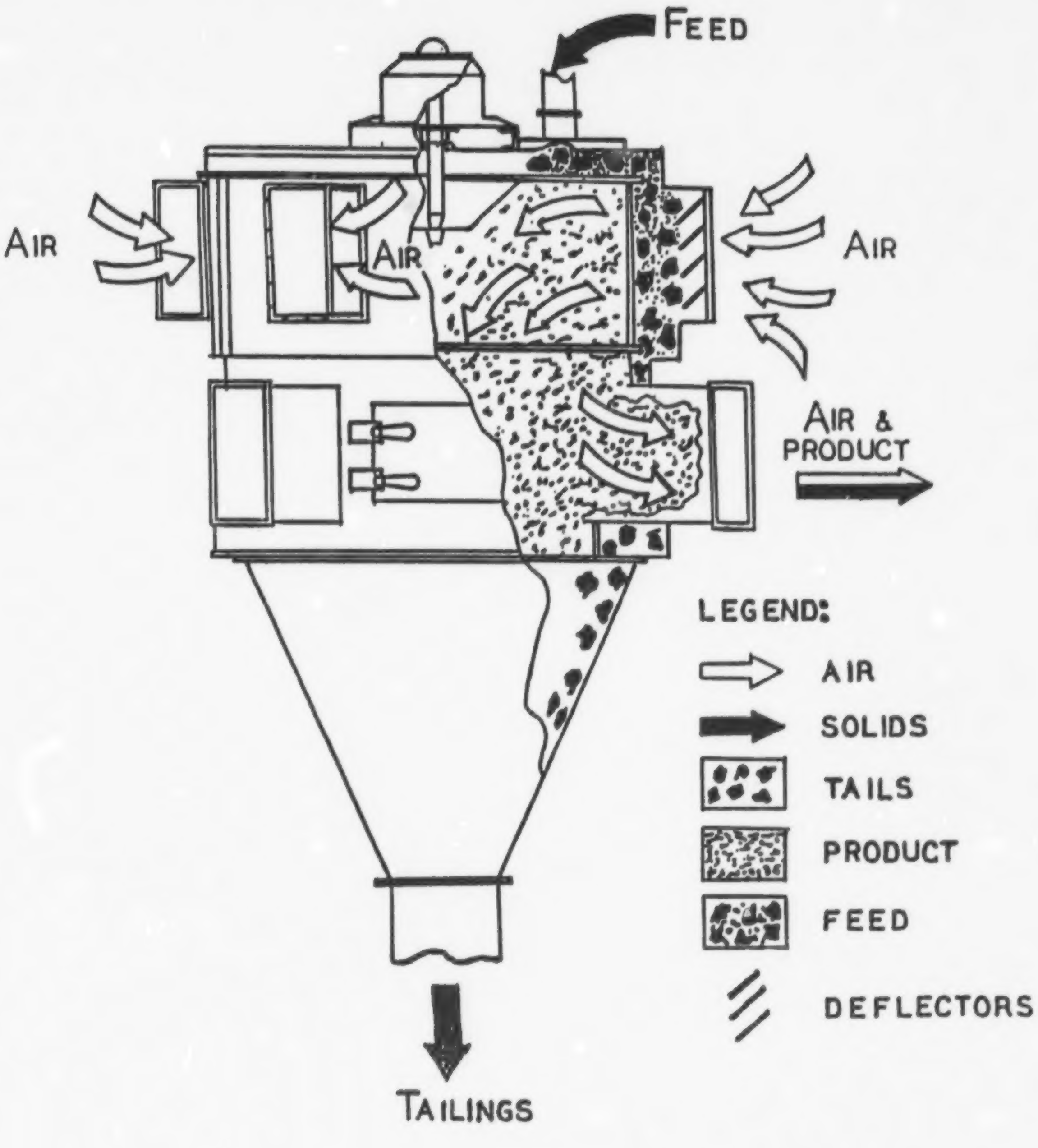
Source: Sturtevant Inc. Product Brochure
SD High Efficiency Air Classifier - 1985

The Sturtevant SD High Efficiency Air Classifier is discussed by Klumpar, I.V., and Zoubov, N.N.(C-4) "New Sturtevant High Efficiency SD Classifiers at Keystone Cement".

Figures 5.2.4-3, 5.2.4-4 and 5.2.4-5 are schematics of the SD classifier with multiple air inlets, as an open system with cyclone collection, and in a closed circuit configuration.

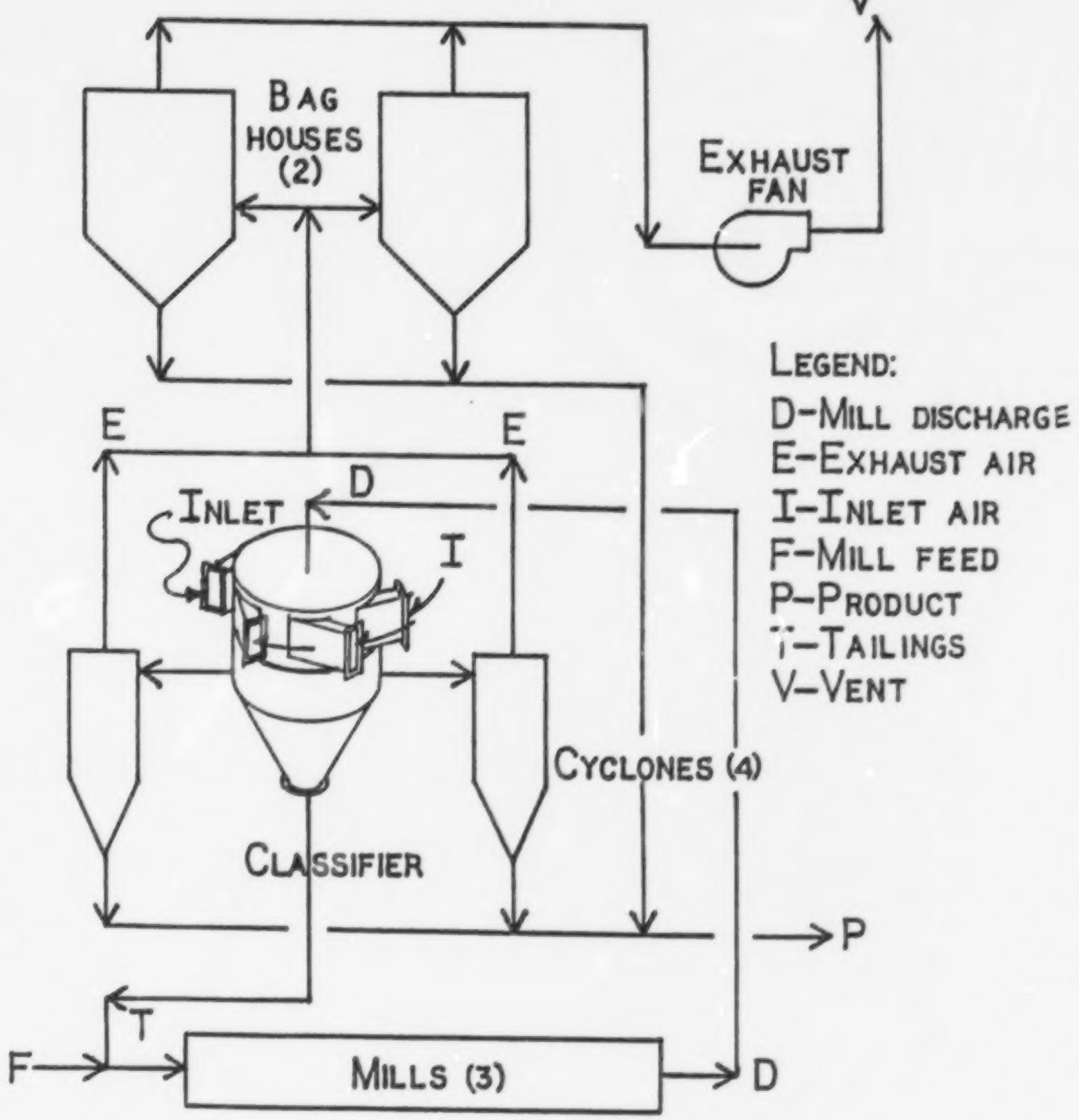
CUT-AWAY OF SD CLASSIFIER WITH MULTIPLE AIR INLETS

FIGURE 5.2.4-3


FEED
AIR
AIR
AIR
AIR & PRODUCT
LEGEND:
AIR
SOLIDS
TAILS
PRODUCT
FEED
DEFLECTORS
TAILINGS

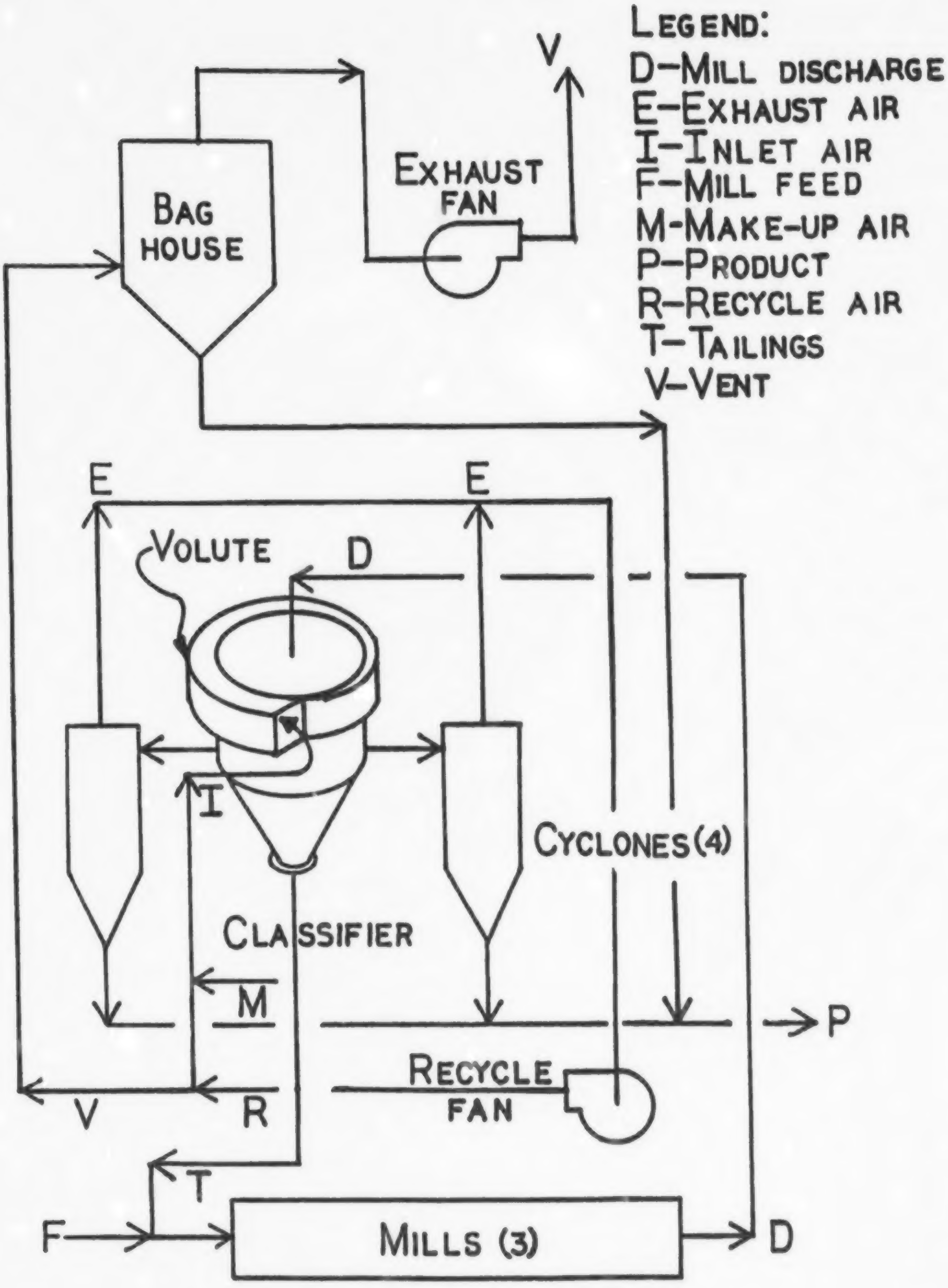
## MILL CIRCUIT WITH OPEN SD CLASSIFIER SYSTEM AND CYCLONE COLLECTION

FIGURE 5.2.4-4


V
BAG HOUSES (2)
EXHAUST FAN
LEGEND:
D-MILL DISCHARGE
E-EXHAUST AIR
I-INLET AIR
F-MILL FEED
P-PRODUCT
T-TAILINGS
V-VENT
E
E
D
INLET
I
CYCLONES (4)
CLASSIFIER
P
T
F
MILLS (3)
D

MILL CIRCUIT WITH CLOSED SD CLASSIFIER SYSTEM

FIGURE 5.2.4-5


LEGEND:
D-MILL DISCHARGE
E-EXHAUST AIR
I-INLET AIR
F-MILL FEED
M-MAKE-UP AIR
P-PRODUCT
R-RECYCLE AIR
T-TAILINGS
V-VENT
V
BAG HOUSE
EXHAUST FAN
E
E
VOLUTE
D
I
CYCLONES(4)
CLASSIFIER
M
P
RECYCLE FAN
V
R
T
F
MILLS (3)
D

## 5.2.5 F.L.SMIDTH & CO. A.S. SEPAX HIGH EFFICIENCY AIR SEPARATOR

F.L. Smidth & Co. started to develop the Sepax high efficiency air classifier in 1982. The first commerical installation was in Spain, in 1984.

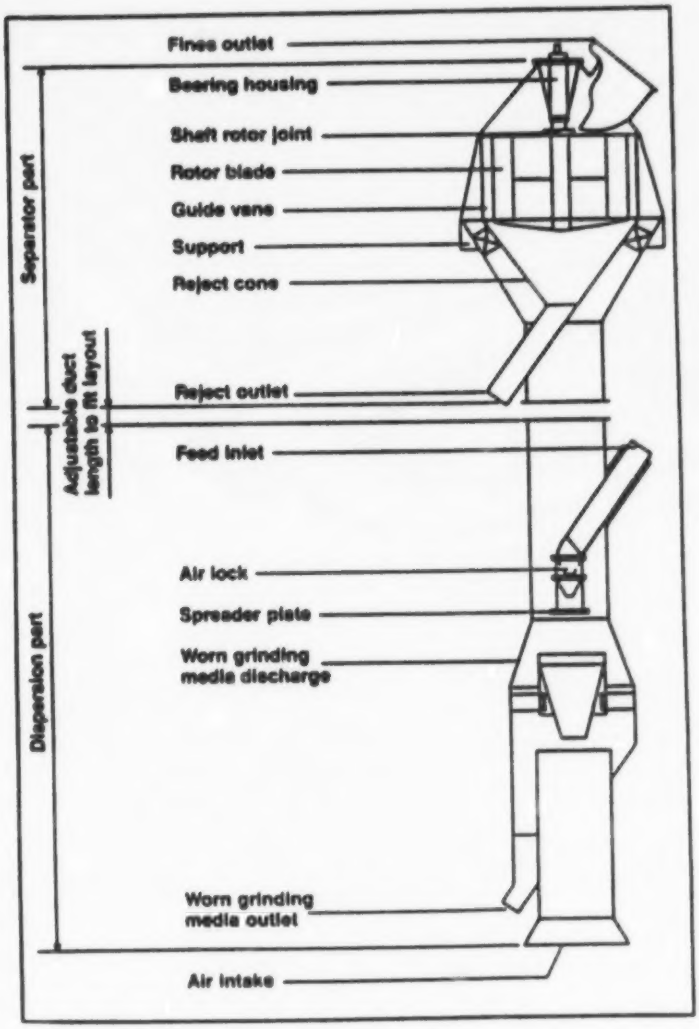
The Sepax separator is unique in that the feed enters from the bottom of the unit rather than the top or side.

Ground cement is introduced via a vertical duct below the separator which is called the dispersion section. Here the material is dispersed in a rising stream of air and delivered to the conical bottom of the separator. (See figure 5.2.5-1). Air with entrained solids passes past a series of vertical guide vanes which ensure even distribution of the solids laden air along the internal separator rotor. The combination of upward air velocity and the speed of rotation of the rotor generates the centrifugal force to spin out the coarse particles. The coarse particles drop out of the air stream into a reject cone and leave the separator via the reject outlet. The fines and air pass through the rotor. Fines are separated from the air by a bag filter, with the air venting to atmosphere. This provides maximum cooling. Another system employs cyclone collectors, with the clean air returned to the separator.

The Sepax separator and its performance is described by S.W. Joergensen(C-1) in his article "Develop High Efficiency Air Separator for cement grinding systems".

## FIGURE 5.2.5-1

## F.L. SMIDTH & CO. A.S.
## SEPAX HIGH EFFICIENCY AIR CLASSIFIERS


Fines outlet
Bearing housing
Shaft rotor joint
Rotor blade
Guide vane
Support
Reject cone
Reject outlet
Feed inlet
Air lock
Spreader plate
Worn grinding media discharge
Worn grinding media outlet
Air intake
Separator part
Adjustable duct length to fit layout
Dispersion part

Source: "Develop High Efficiency Air Separator for cement grinding systems". Joergenson, S.W., Pit & Quarry, July 1985.

### 5.2.6 KRUPP POLYSIUS - CYCLOPOL AIR SEPARATOR

The Cyclopol air separator is a recent design by Krupp Polysius, and is a replacement for the more conventional "Turbopol" air separator.

Two different configurations are available. These are:
(a) a separator with product collection using multiple cyclones; or (b) a separator with product collection using a bag filter. The latter method is employed if cement cooling is required.

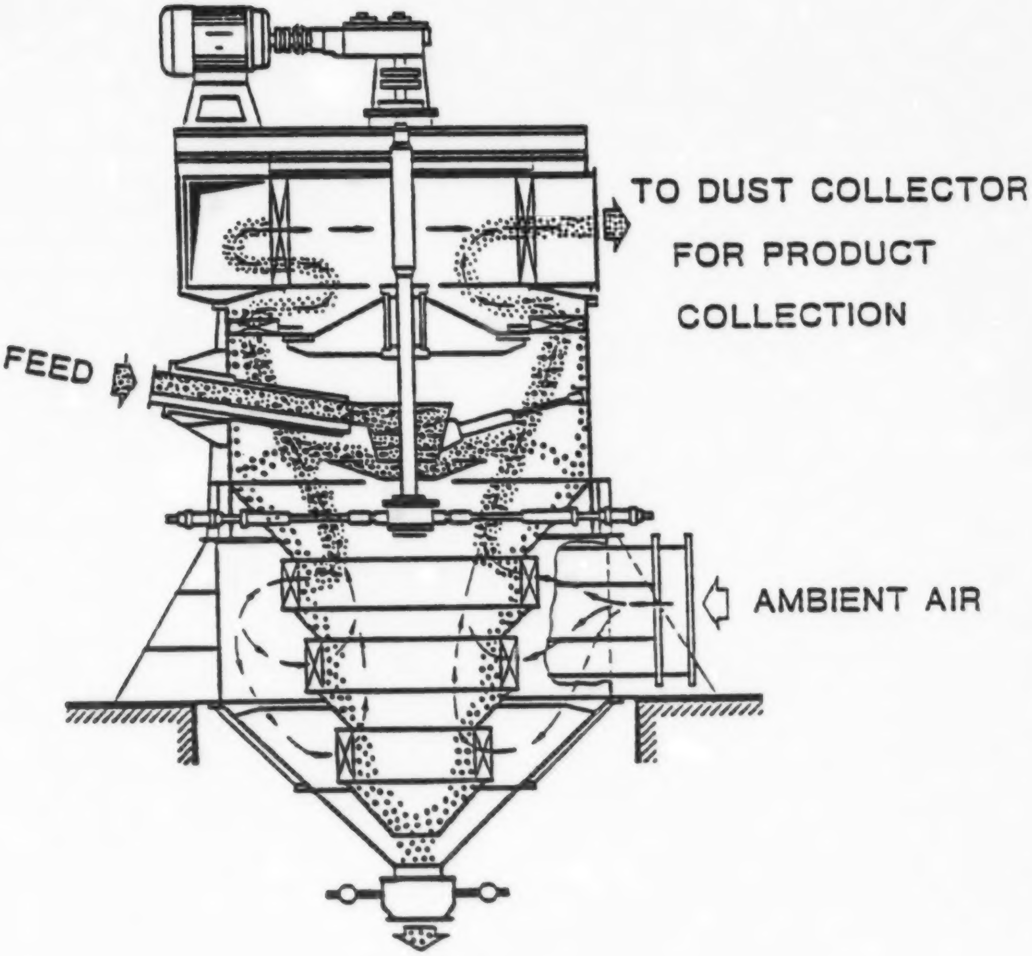
The operation of the Cyclopol single pass high efficiency air separator is shown in figure 5.2.6-1.

Feed entering the separator housing from the side drops on to a distributor plate. Fresh ambient air enters the classifier tangentially below the distributor plate through a series of louvers located in the lower part of the classifier. Here, it blends with mill outlet air. Fines contained in the feed and entrained in the mill air are separated and carried out with the separating air current and collected in a bag filter or in cyclones. Coarse rejects drop out against the rising air stream, are discharged from the bottom of the classifier, and returned to the grinding mill.

FIGURE 5.2.6-1

KRUPP POLYSIUS - CYCLOPOL

## SINGLE PASS HIGH EFFICIENCY SEPARATOR


TO DUST COLLECTOR
FOR PRODUCT
COLLECTION
FEED
AMBIENT AIR

REJECTS

## 6.0 CLASSIFIER TESTING

For the purpose of demonstrating the impact high efficiency classifiers may have on air classification of cement, tests were conducted with two types of air classifiers.

Feed materials selected for these tests were obtained from a typical ball mill used to "finish grind" cement and from rejects produced by two conventional air classifiers operating in closed circuit with the ball mill.

The objectives of the tests were to demonstrate that high efficiency air classifiers are significantly more effective than conventional units in extracting cement with the desired particle size distribution and Blaine surface area from a typical mill discharge.

Secondly, it was to demonstrate that rejects, as produced by conventional air separators, contain a significant "product fraction" that can be extracted with high efficiency air classification equipment.

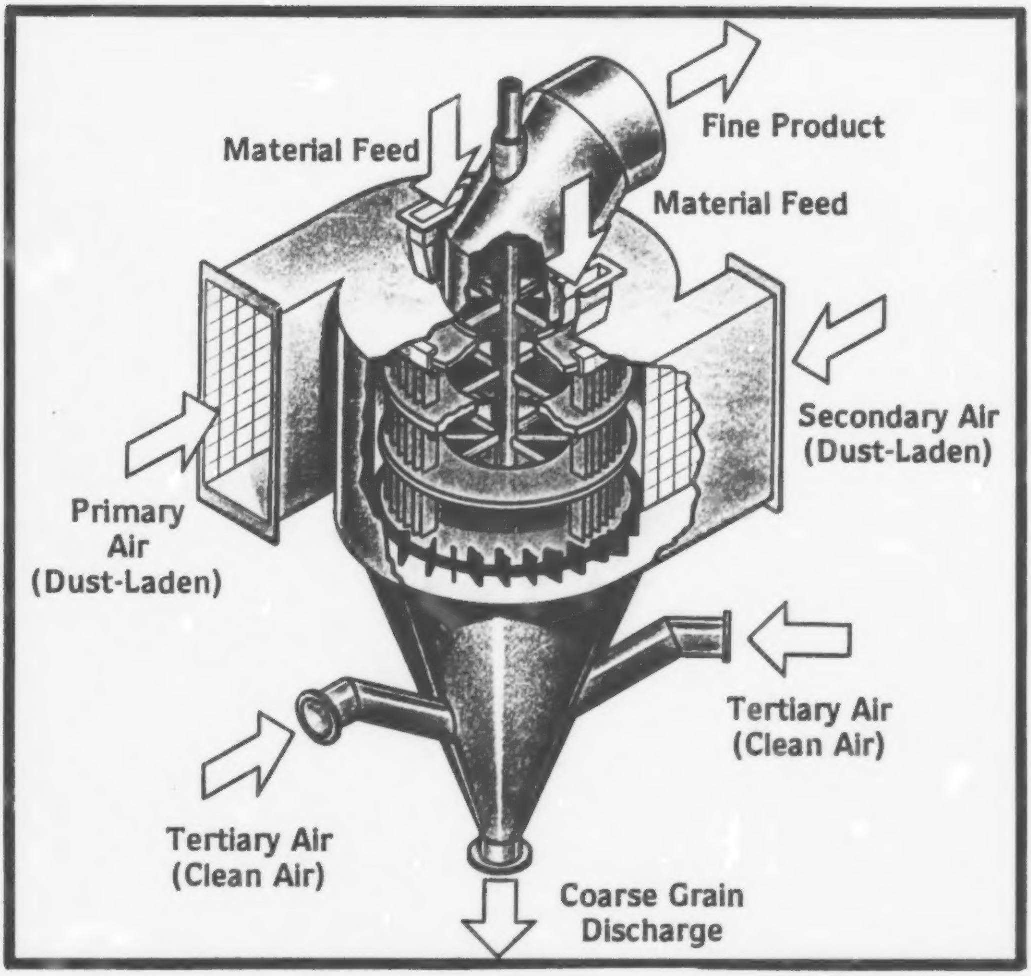
Two high efficiency air classifiers were selected for this purpose. The first one was the O-Sepa classifier which is of Japanese design and produced in North America by the Fuller Traylor Company, Bethlehem, Pennsylvania. The tests were conducted by personnel of the Fuller Traylor Company at their development centre. The O-Sepa, N-20, pilot plant air classifier was used for the tests.

The following is a description of the air classifier, it's auxiliary equipment, the test procedure and a schematic of the circuit.

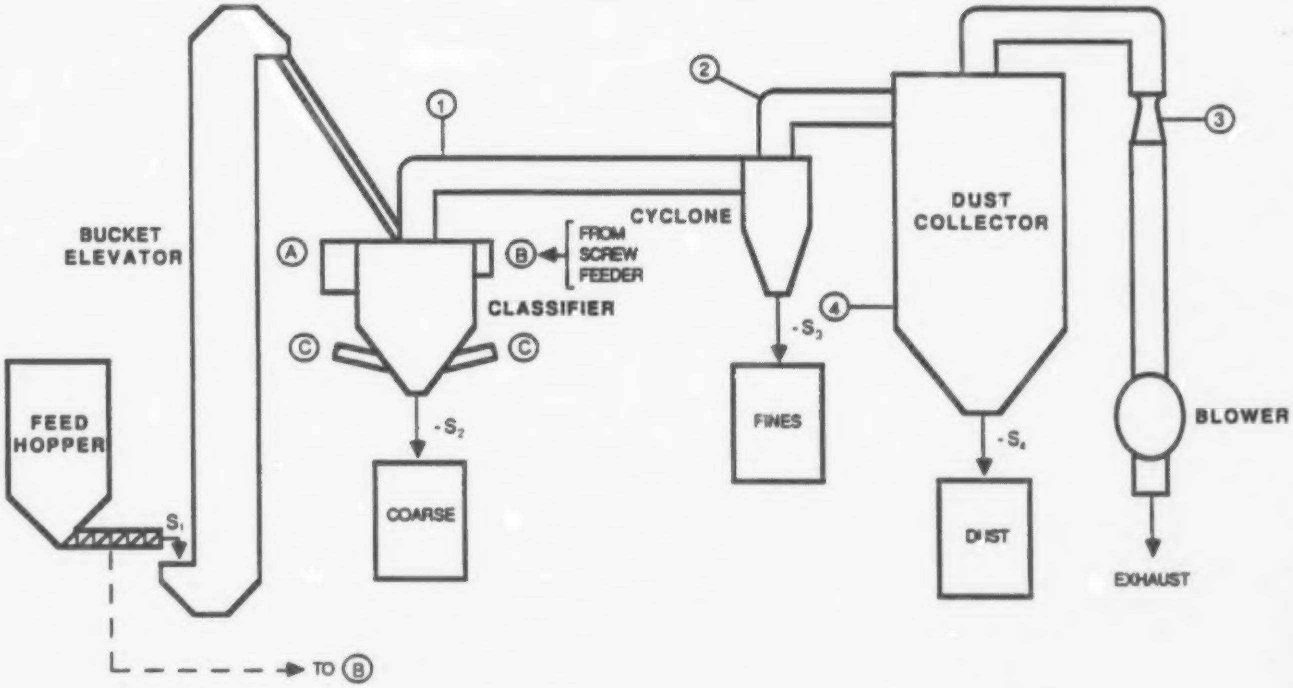
The O-Sepa, N-20, pilot plant circuit consists of a feed bin (20 cu.ft.) attached to a variable speed screw feeder that discharges to a bucket elevator. The bucket elevator lifts the material to dual separator feed spouts, below which a rotating distributing rotor disperses the material into the classifying air stream. The rotor speed is controlled by a variable frequency AC drive. Air flow is adjusted by a variable speed (DC) drive on a positive displacement blower, acting as a suction source. Product (fine fraction) is conveyed from the O-Sepa in the air stream to a cyclone and baghouse collection system, with rotary air locks below each. The coarse fraction falls through a gravity operated tipping valve into a collection drum.

For the tests composite samples were selected over about a five minute test period, with the weight and sampling time for each separator product used for mass flow calculation. These composite samples were then split into small representative samples for analysis. All testing was conducted at a nominal air flow of 20 $m^3$/minute, as measured with a venturi located on the clean gas side of the baghouse, just ahead of the blower inlet. Air distribution into the O-Sepa was a nominal 70% primary, (used to vent the elevator), 20% secondary, (venting the feed screw discharge), and 10% tertiary, (clean air) in the rejects cone. Ambient temperature of the air during testing was 78-80°F. The separator feed rate was unchanged during testing, the differences in total feed rate, calculated from product rates, resulted from flow variations at different bins.

FULLER O'SEPA AIR CLASSIFIER CIRCUIT FIGURE 6.0-1


Fine Product
Material Feed
Material Feed
Secondary Air
(Dust-Laden)
Primary
Air
(Dust-Laden)
Tertiary Air
(Clean Air)
Tertiary Air
(Clean Air)
Coarse Grain
Discharge

## FULLER O'SEPA AIR CLASSIFIER CIRCUIT FIGURE 6.0-2


BUCKET ELEVATOR
FEED HOPPER
$S_1$
TO Ⓑ
①
Ⓐ
Ⓑ
FROM SCREW FEEDER
CLASSIFIER
Ⓒ
Ⓒ
$-S_2$
COARSE
②
CYCLONE
$-S_3$
FINES
DUST COLLECTOR
④
$-S_4$
DUST
③
BLOWER
EXHAUST

LEGEND:

A - PRIMARY AIR - IN
B - SECONDARY AIR - IN
C - TERTIARY AIR - IN

1 - 6" TO 8" $H_2O$
2 - 14" TO 16" $H_2O$
3 - 3.4" $H_2O$
4 - 18" TO 20" $H_2O$

$S_1$ - FEED
$S_2$ - COARSE
$S_3$ - FINES
$S_4$ - DUST

## 6.1 Tests on Cement Mill Discharge Using an O'Sepa, N-20, Pilot Plant Sized High Efficiency Classifier

### 6.1.1 Feed Materials

The feed materials for the tests were supplied by Canada Cement Lafarge. The feed materials, i.e. cement mill discharge and rejects from the classifier, were analyzed for percentage passing 325 mesh, (45) micron screen and for Blaine surface area $cm^2$/gram.

The following results were obtained:

| Sample | Blaine Surface Area $cm^2/g$ | % -325 Mesh |
|---|---|---|
| Cement Mill Discharge | 1929 | 54 |
| Separator Rejects | 1254 | 40 |

A separate series of classification tests were conducted on each of the two feed materials, using the procedure and equipment as outlined previously.

### 6.1.2 Test Series 1

Test Series 1 used cement mill discharge as feed to the O-Sepa, N-20, high efficiency air classifier. Tests were conducted at constant air flows and similar feed rates. The main variable was rotor speed. Results from Test Series 1 are shown in tabular form on Table 6.1.1-1.

The objective of Test Series 1 was to produce cement products with a Blaine surface area of 3700 $cm^2/g$, ±100.

## CEMENT CLASSIFICATION TEST

Pilot Plant Sized "State of the Art" O-Sepa,
N-20, Air Classifier

### TABLE 6.1.1-1

Test Series 1

Feed Material — Cement Mill Discharge

54% -325

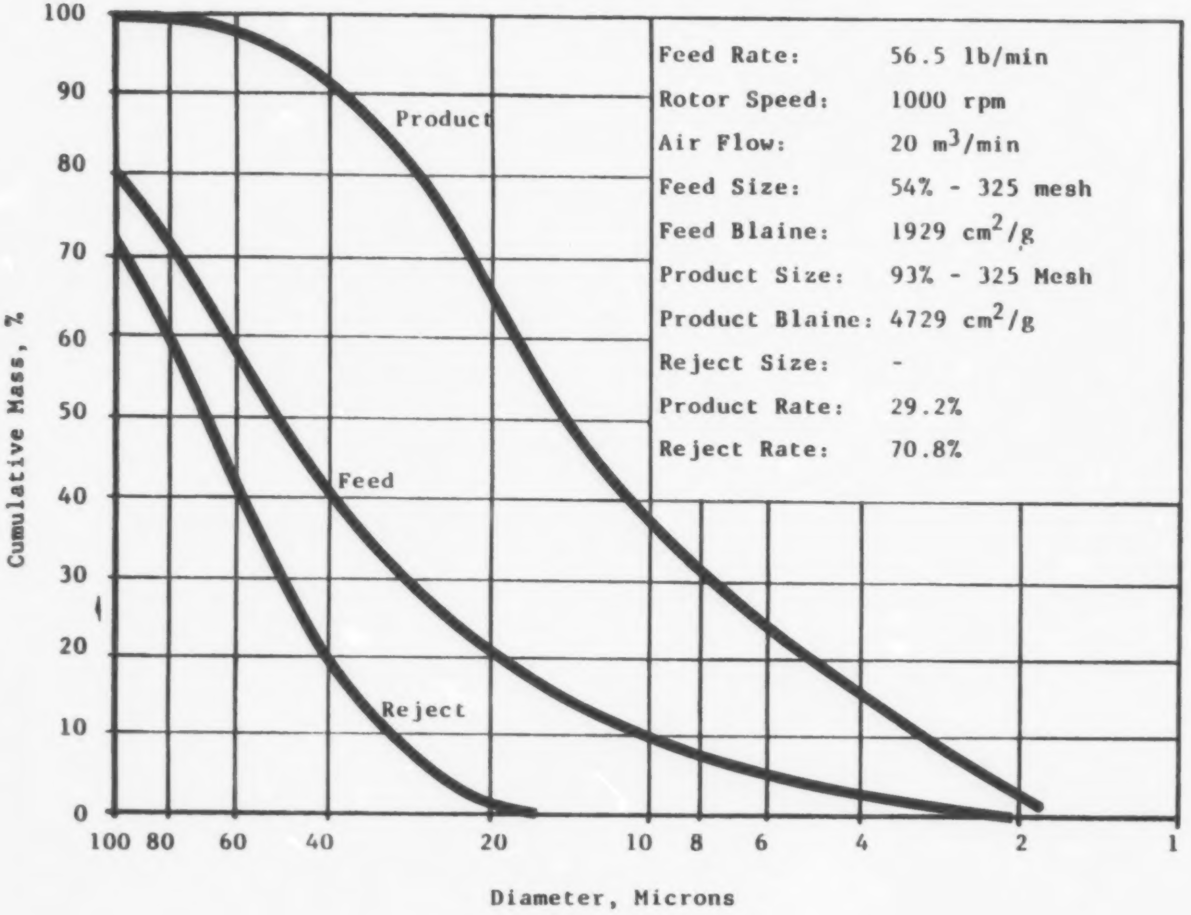
Blaine 1929 cm²/g

| | | Test Series 1 | | |
|---|---|---|---|---|
| | | Run 1 | Run 2 | Run 3 |
| FEED RATE | (lb/min) | 56.5 | 56.4 | 61.9 |
| ROTOR SPEED | (rpm) | 1000 | 700 | 730 |
| AIR FLOW | ($m^3$/min) | 20 | 20 | 20 |
| PRODUCT SIZE | (% -325) | 93.0 | 87.0 | 88.5 |
| REJECT SIZE | (% -325) | | 24.0 | |
| BLAINE | ($cm^2$/g) | 4729 | 3664 | 3816 |
| PRODUCT RATE % | | 29.2 | 44.7 | 40.5 |
| REJECT RATE % | | 70.8 | 55.3 | 59.5 |

Figures 6.1.1-2,-3,-4, each show the particle size distributions of feed, product and rejects as obtained in Test Series 1, Runs 1, 2, and 3. Figure 6.1.1-5 indicates the Tromp Curve on a product basis for Test Run #2.

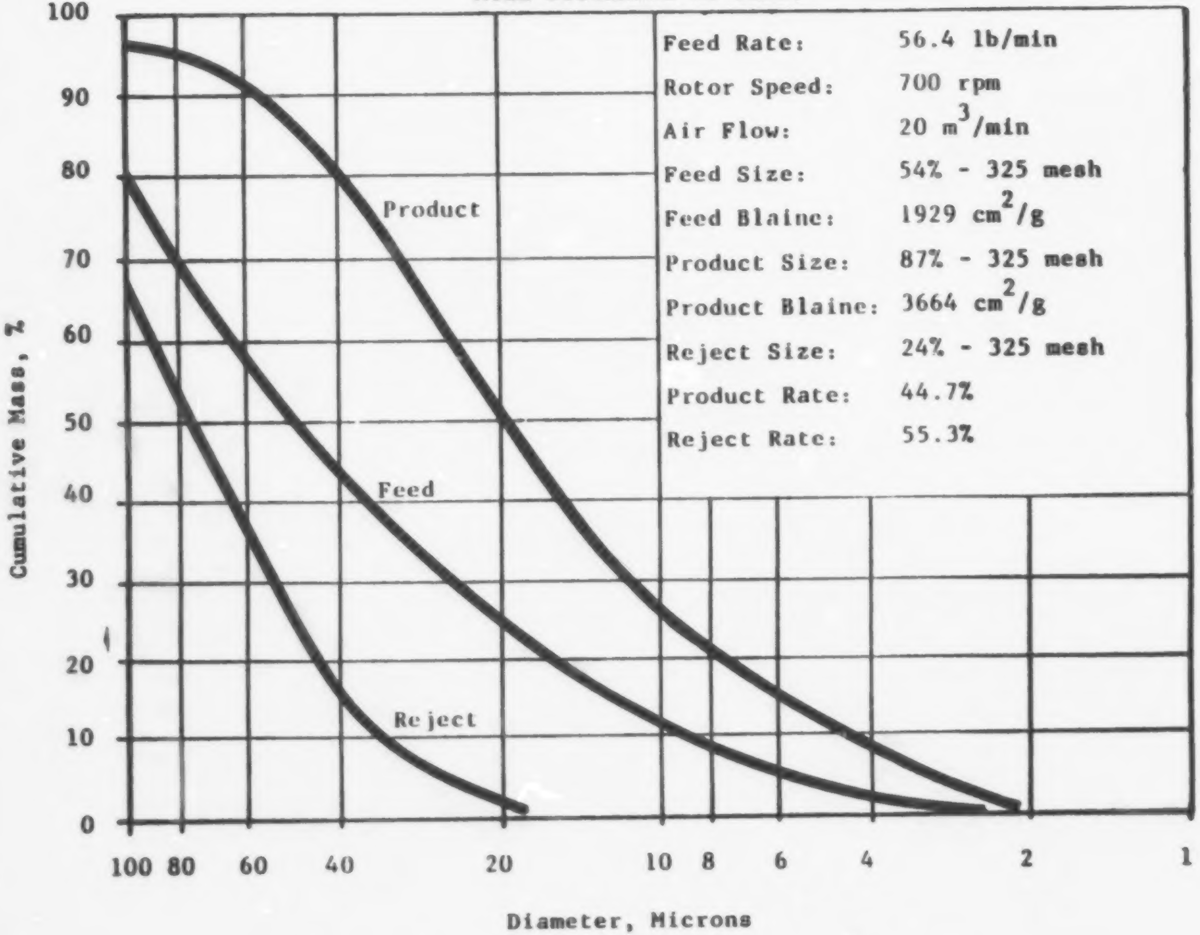
FIGURE 6.1.1-2

PROJECT 5174 - ACTIVITY 2
CLASSIFICATION TEST SERIES 1 - RUN 1
(USING "STATE OF THE ART" CLASSIFIER AND CEMENT
MILL DISCHARGE AS FEED)



## FIGURE 6.1.1-3

PROJECT 5174 - ACTIVITY 2
CLASSIFICATION TEST SERIES 1 - RUN 2
(USING "STATE OF THE ART" CLASSIFIER AND CEMENT MILL DISCHARGE AS FEED)

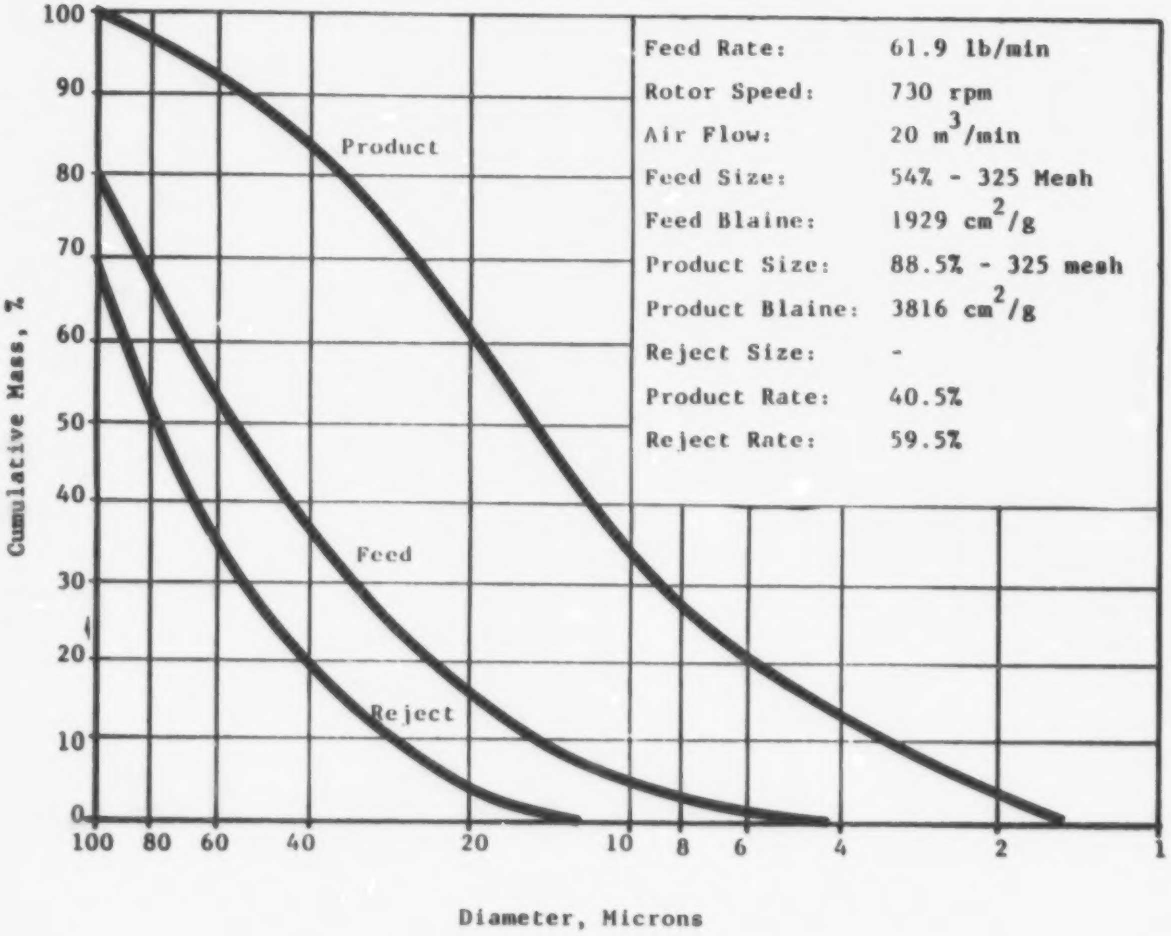


Feed Rate: 56.4 lb/min
Rotor Speed: 700 rpm
Air Flow: 20 $m^3$/min
Feed Size: 54% - 325 mesh
Feed Blaine: 1929 $cm^2$/g
Product Size: 87% - 325 mesh
Product Blaine: 3664 $cm^2$/g
Reject Size: 24% - 325 mesh
Product Rate: 44.7%
Reject Rate: 55.3%

## FIGURE 6.1.1-4

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 1 - RUN 3
(USING "STATE OF THE ART" CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)

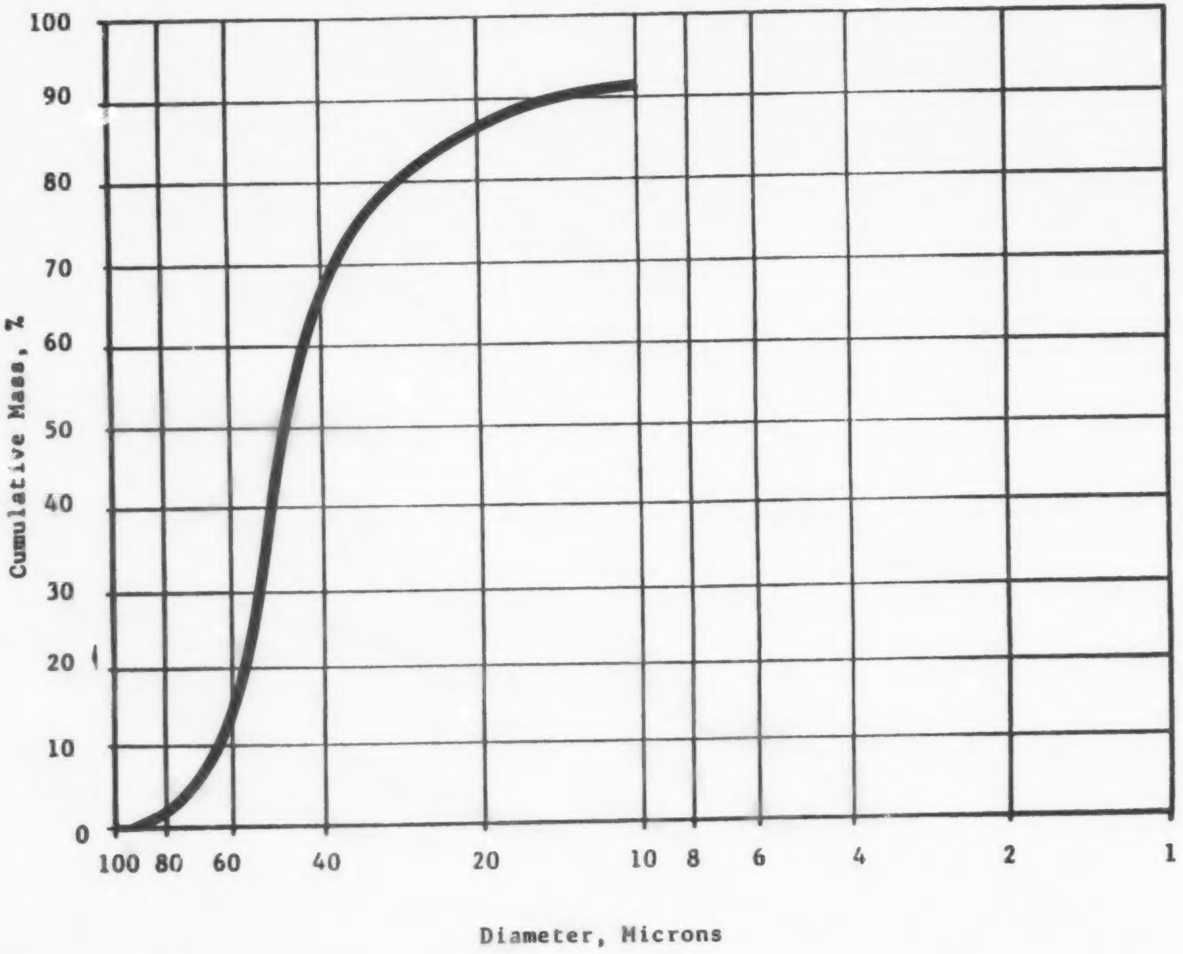


| | |
|---|---|
| Feed Rate: | 61.9 lb/min |
| Rotor Speed: | 730 rpm |
| Air Flow: | 20 $m^3$/min |
| Feed Size: | 54% - 325 Mesh |
| Feed Blaine: | 1929 $cm^2$/g |
| Product Size: | 88.5% - 325 mesh |
| Product Blaine: | 3816 $cm^2$/g |
| Reject Size: | - |
| Product Rate: | 40.5% |
| Reject Rate: | 59.5% |

## FIGURE 6.1.1-5

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 1 - RUN 2
(USING "STATE OF THE ART" CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)
TROMP CURVE - PRODUCT BASIS



### 6.1.3 Discussion of Test Results

Of the three tests conducted, Runs 2 and 3 produced products with Blaine surface areas in the range of the desired product, i.e. 3700 $cm^2/g$ ± 100 $cm^2/g$.

Run 2, most closely approximated the desired product and provided a production rate of 44.7%.

Each of the products and rejects were analyzed for particle size distribution by personnel from Witteck Development, using the Sedigrah "5000" particle size analyzer. Run 2 data was further analyzed and a Tromp curve, on a product basis was prepared.

Calculations of classifier efficiency at 45, 20 and 10 microns were made on Run 2, with the following results:

| | Classifier Efficiency Series 1, Run 2 | | |
|---|---|---|---|
| | At 45 Microns | At 20 Microns | At 10 Microns |
| (Calculated) % Recovery | 47.6 | 45.6 | 46.1 |
| (Calculated) % Oversize | 52.4 | 54.4 | 53.9 |
| (Calculated) % Efficiency- Relative to Product | 76.7 | 91.2 | 99.9 |
| Ratio: Tons of Feed/ Tons of Product | 2.1 | 2.19 | 2.17 |
| % Circulating Load | 110 | 119 | 117 |

These results indicate a good efficiency across the particle size spectrum. A useful rule, to quickly assess efficiency, is to compare actual product yield with theoretical product yield at the desired particle size. For instance, if a product is desired with ninety (90) percent passing 325 mesh (45 micron) from a feed with fifty-four (54) percent passing 325 mesh, then the theoretical maximum product yield would be:

$$\text{Efficiency} = 54.0 \times \frac{1.0}{0.9} = 60\%$$

for a product with 90% Passing a 325 mesh (45 micron) screen.

If actual yield from classification is 44.7%, then classifier efficiency can be expressed by:

$$\frac{\text{Actual Yield}}{\text{Theorectical Yield}} = \frac{44.7}{60.0} = 74.5\%$$

In Run 2 product quality was not as specified, i.e. 90% passing 325 mesh (45 micron), but rather 87% passing 325 mesh.

Actual yield of material passing 325 mesh (45 micron) is:

0.87 x 44.7% = 38.89% of 100% passing -325 mesh (45 micron)

Allowing for (ten) 10% of +325 mesh (45 micron) material in the product, the true yield of "specified" product can be calculated as:

Yield of 100% passing -325 mesh (45 micron) screen =

$$38.89 \times \frac{1.0}{0.9} = \underline{43.21\%}$$

Assuming an adjustment was made to the classifier to reduce the amount of +325 mesh (45 micron) material to (ten) 10%, the product yield would have been reduced slightly from the "as calculated".

Results calculated from sedigraph analysis of feed, product and rejects, compare quite well with measured recovery. The calculated classifier efficiency shows conclusively that extraction of fine particles, i.e. particles finer than 20 micron, is excellent. Rejects are virtually free of fine particles, indicating that the material was well dispersed during classification and no fines were adhering to coarser particles.

Runs 1 & 3 are self explanatory. The effect of rotor speed on product fineness, and subsequent product yield can be readily seen.

## 6.2 Tests on Rejects From Conventional Separator With An O-Sepa, N-20, Pilot Plant Sized High Efficiency Air Classifier

### 6.2.1 Test Series 2

A total of five (5) classification tests were conducted using rejects from a conventional air separator.

The purpose of these tests was to demonstrate that it is possible to extract significant amounts of product from rejects produced by conventional air separators.

All tests were conducted at similar feed rates and constant airflows. The only variable was rotor speed. Product requirements were identical to the previous tests using mill discharge as feed material.

Test results are shown in tabular form on Table 6.2.1-1.

## CEMENT CLASSIFICATION TEST

### Pilot Plant Sized "State of the Art"
### O'Sepa, N-20, High Efficiency Air Classifier

### TABLE 6.2.1-1
### Test Series 2

| Feed Material | Rejects from Conventional Cement Air Classifier |
|---|---|
| 40% -325<br>Blaine 1254 ($cm^2/g$) | |

| | | Run # | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| FEED RATE | (lb/min) | 51.3 | 61.2 | 61.3 | 66.7 | 64.1 |
| ROTOR SPEED | (rpm) | 900 | 750 | 815 | 780 | 800 |
| AIR FLOW | ($m^3/min$) | 20 | 20 | 20 | 20 | 20 |
| PRODUCT SIZE | (%-325) | 90.4 | 85.8 | 88.2 | 86.2 | 87.2 |
| REJECT SIZE | (%-325) | - | - | - | - | 17.5 |
| BLAINE | ($cm^2/g$) | 4226 | 3302 | 3967 | 3494 | 3697 |
| PRODUCT RATE | % | 29.0 | 30.7 | 26.9 | 25.8 | 26.4 |
| REJECT RATE | % | 71.0 | 69.3 | 73.1 | 74.2 | 73.6 |

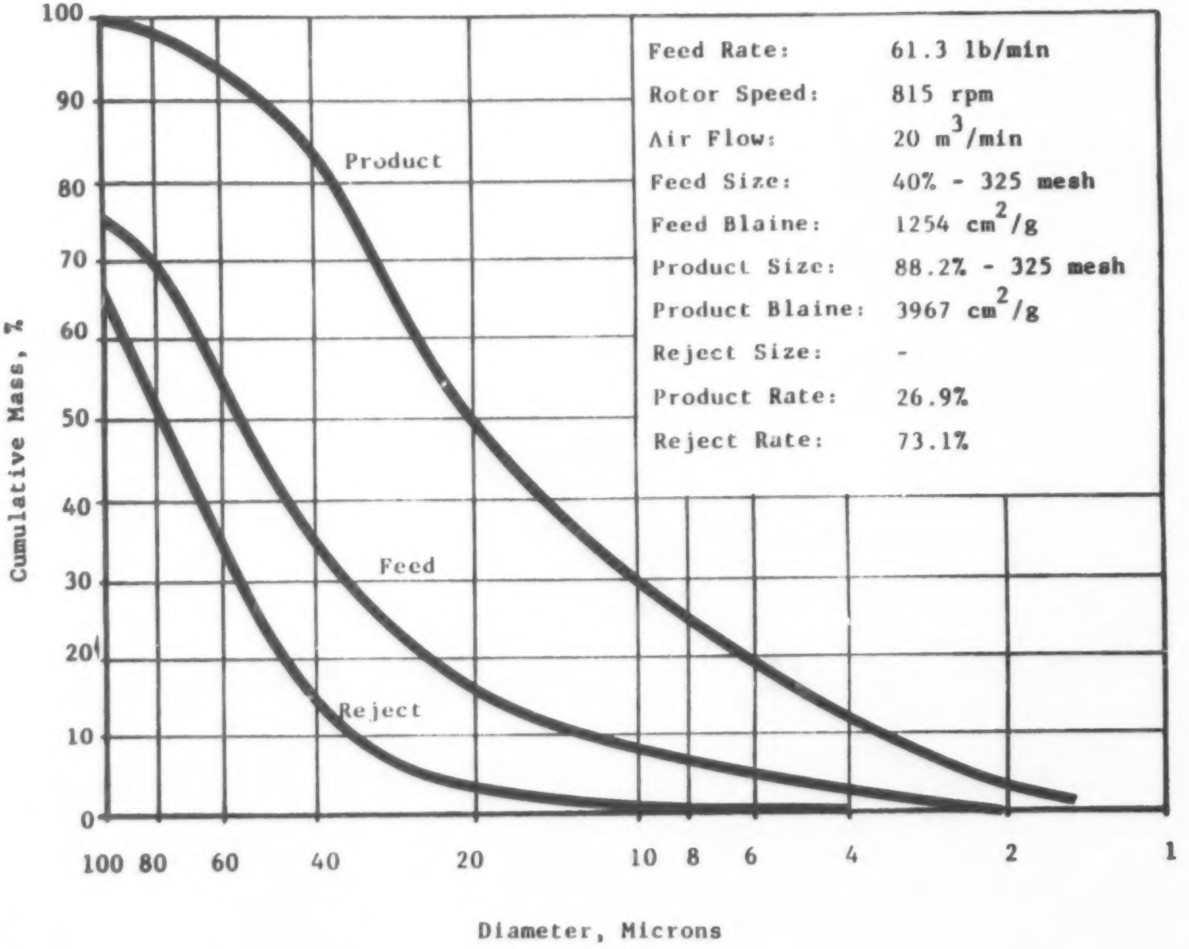
### 6.2.2 Discussion of Test Results

Of the five (5) tests conducted in Test Series 2, Run 5 produced a product with a Blaine surface area of 3700 $cm^2/g$. Run 3 produced a product with a Blaine of 3967 $cm^2/g$. All other tests produced products either too fine or too coarse.

Feed, product and rejects of Test Series 2 Runs 3 & 5 were analyzed for their particle size distribution using the sedigraph 5000 particle size analyzer. From the sedigraph analysis classifier efficiency was calculated and a Tromp curve prepared expressing the fractional recoveries. These are shown on Figures 6.2.1-2, 6.2.1-3, and 6.2.1-4.

## FIGURE 6.2.1-2

PROJECT 5174 - ACTIVITY 2
CLASSIFICATION TEST SERIES 2 - RUN 3
(USING "STATE OF THE ART" CLASSIFIER AND
REJECT FROM CONVENTIONAL CEMENT CLASSIFIER AS FEED)



Feed Rate: 61.3 lb/min
Rotor Speed: 815 rpm
Air Flow: 20 $m^3$/min
Feed Size: 40% - 325 mesh
Feed Blaine: 1254 $cm^2$/g
Product Size: 88.2% - 325 mesh
Product Blaine: 3967 $cm^2$/g
Reject Size: -
Product Rate: 26.9%
Reject Rate: 73.1%

FIGURE 6.2.1-3

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 2 - RUN 5

(USING "STATE OF THE ART" CLASSIFIER AND
REJECT FROM CONVENTIONAL CEMENT CLASSIFIER AS FEED)

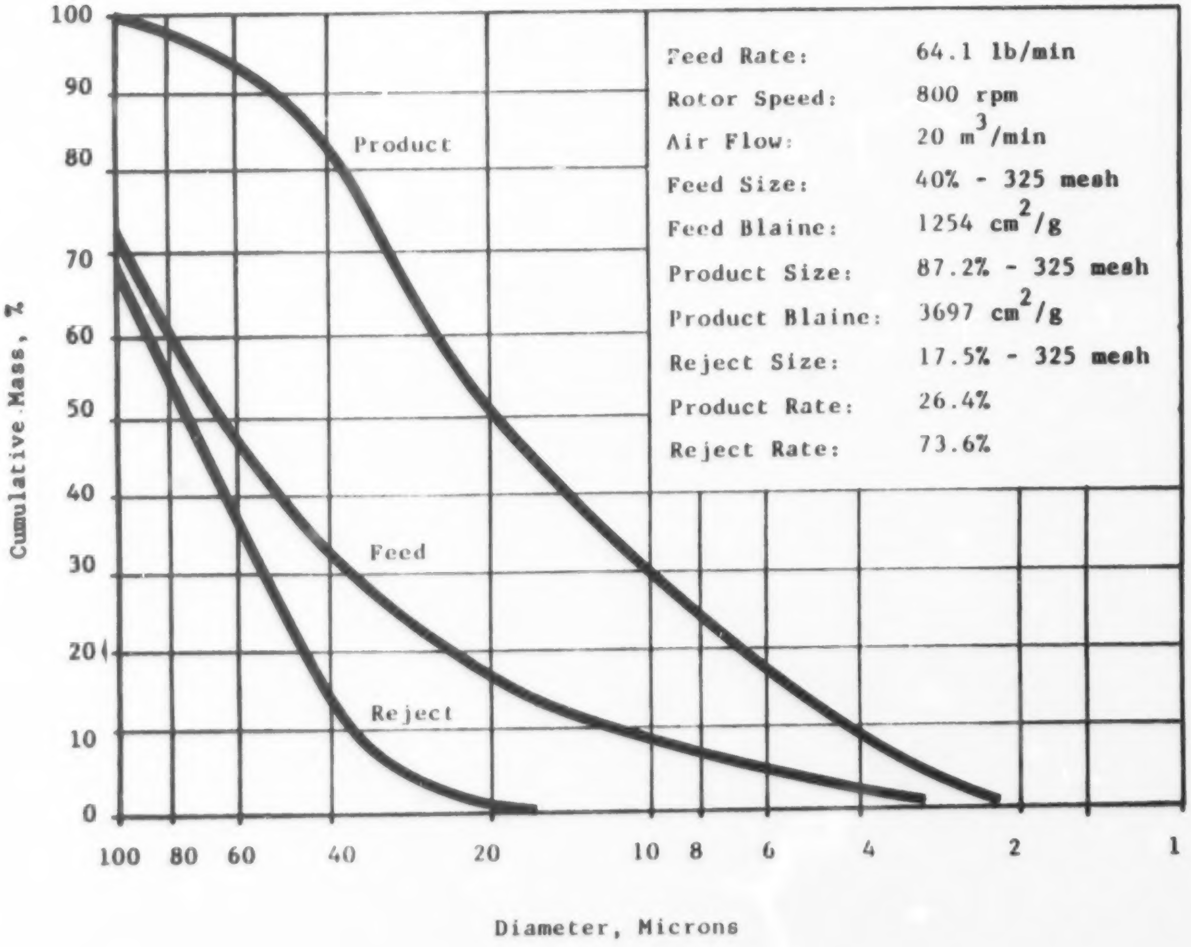
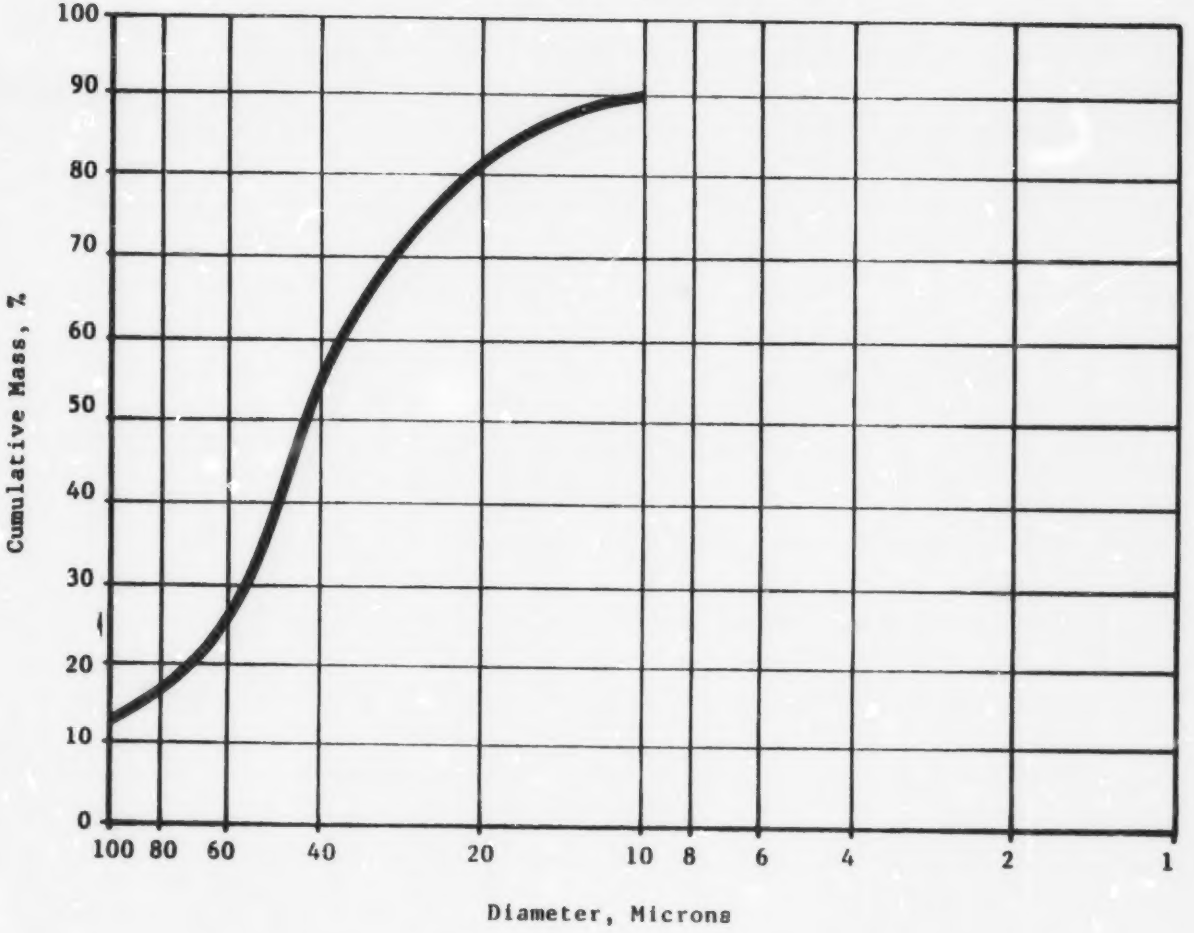


FIGURE 6.2.1-4

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 2 - RUN 5
(USING "STATE OF THE ART" CLASSIFIER AND
REJECT FROM CONVENTIONAL CEMENT CLASSIFIER AS FEED)
TROMP CURVE - PRODUCT BASIS



It is interesting to note that while feed rates to the classifier were similar to the tests in Series 1 and at identical airflows, a higher rotor speed i.e. 800 rpm (Test Series 2, Run 5) versus 700 rpm in (Test Series 1, Run 2) is required to produce the same product quality which indicates that with otherwise stable operating conditions, (air flows) and feed rates), when the particle size of the feed changes, rotor speed will need to be increased for coarser feed and reduced for finer feed material.

This is explained by the fact that at similar feed rates, but with coarser feed, there are fewer particles (lower grain loading) in the air stream, resulting in higher air particle velocities. To make a separation at the same cut point requires a greater centrifugal force to be generated in the classifying zone to overcome the increased drag forces of the air.

This is further illustrated by comparing tests at similar rotor speeds (Test Series 1, Run 3 with Test Series 2, Run 2), but using different feed quality.

| | Rotor Speed | Feed Rate lb/min | Product Blaine |
|---|---|---|---|
| Test 1, Run 3 | 730 rpm | 61.9 | ($3816\ cm^2/g$) |
| Test 2, Run 2 | 750 rpm | 61.2 | ($3302\ cm^2/g$) |
| Test 2, Run 5 | 800 rpm | 64.1 | ($3697\ cm^2/g$) |

The only difference between these tests is the particle size difference of the feed material. At virtually identical rotor speeds and feed rate, the coarse feed material produced a much lower Blaine. Yet, the percentage passing 325 mesh (45 micron) was relatively similar. An increase of only 50 rpm to 800 rpm, resulted in a significant increase in Blaine, (Test Series 2, Run 5).

This demonstrates the sensitivity of the relationship between feed quality and rotor speed, as well as the effect of rotor speed alone with constant feed quality. It is, therefore, essential to exercise diligent control over rotor speed as well as maintaining constant particle size distribution of feed to the classifier.

A calculation of classifier efficiency at 325 mesh (45 micron) gave the following results:

| | Classifier Efficiency<br>Test Series 2, Run 5<br>At -325 mesh (45 Micron) |
|---|---|
| Calculated % Recovery | 32.2 |
| Calculated % Oversize | 67.8 |
| Calculated % Efficiency Relative to Product | 70.19 |
| Ratio: Tons of Feed/Ton of Product | 3.10 |
| % Circulating Load | 210 |

The percentage of material in the feed passing 325 mesh (45 micron) is forty percent (40%). The theoretical maximum yield, allowing ten percent (10%) of material to be retained on 325 mesh (45 micron) is:

$$40.0 \times \frac{1.0}{0.9} = 44.44\%$$

If actual product yield is 32.7% then the classifier efficiency can be expressed as being:

$$\frac{\text{Actual Yield}}{\text{Theoretical Yield}} = \frac{32.7}{44.44} = 73.6\%$$

The actual product contained 12.8% retained on 325 mesh (45 micron) rather than the specified ten percent (10%) retained on 325 mesh (45 micron). This, when recalculated to a product with ten percent (10%) retained on 325 mesh (45 micron), reduces classifier efficiency to approximately seventy-one percent (71%). To achieve this requires an increase in rotor speed, which will result in a lower percentage of +325 mesh (45 micron) material and also an increase in Blaine surface area.

The effect of higher rotor speed is illustrated in Test series 2, Run 1. At higher (900 rpm) rotor speed, the percent retained on 325 mesh (45 micron) is reduced to the required level, but is accompanied by an increase in Blaine surface area to 4226 ($cm^2/g$).

These tests provide conclusive evidence that rejects from a conventional air classifier contain significant amounts of extractable product. From the feed material used in these tests, a product yield in the range of twenty-five (25) to thirty (30) percent is a realistic expectation; if, for instance, a high efficiency classifier was used as a second stage classifier after a conventional air separator. This concept has merit, particularly, if space for a second classifying unit is available.

## 6.3 Tests on Cement Mill Discharge, using a Microsizer MS-5 Pilot Plant Sized High Efficiency Air Classifier

### 6.3.1 Description of the Microsizer MS-5 Air Classifier

A pilot plant sized MS-5* high efficiency air classifier was used to conduct air classification tests on cement mill discharge and rejects from a conventional air separator used in production of cement.

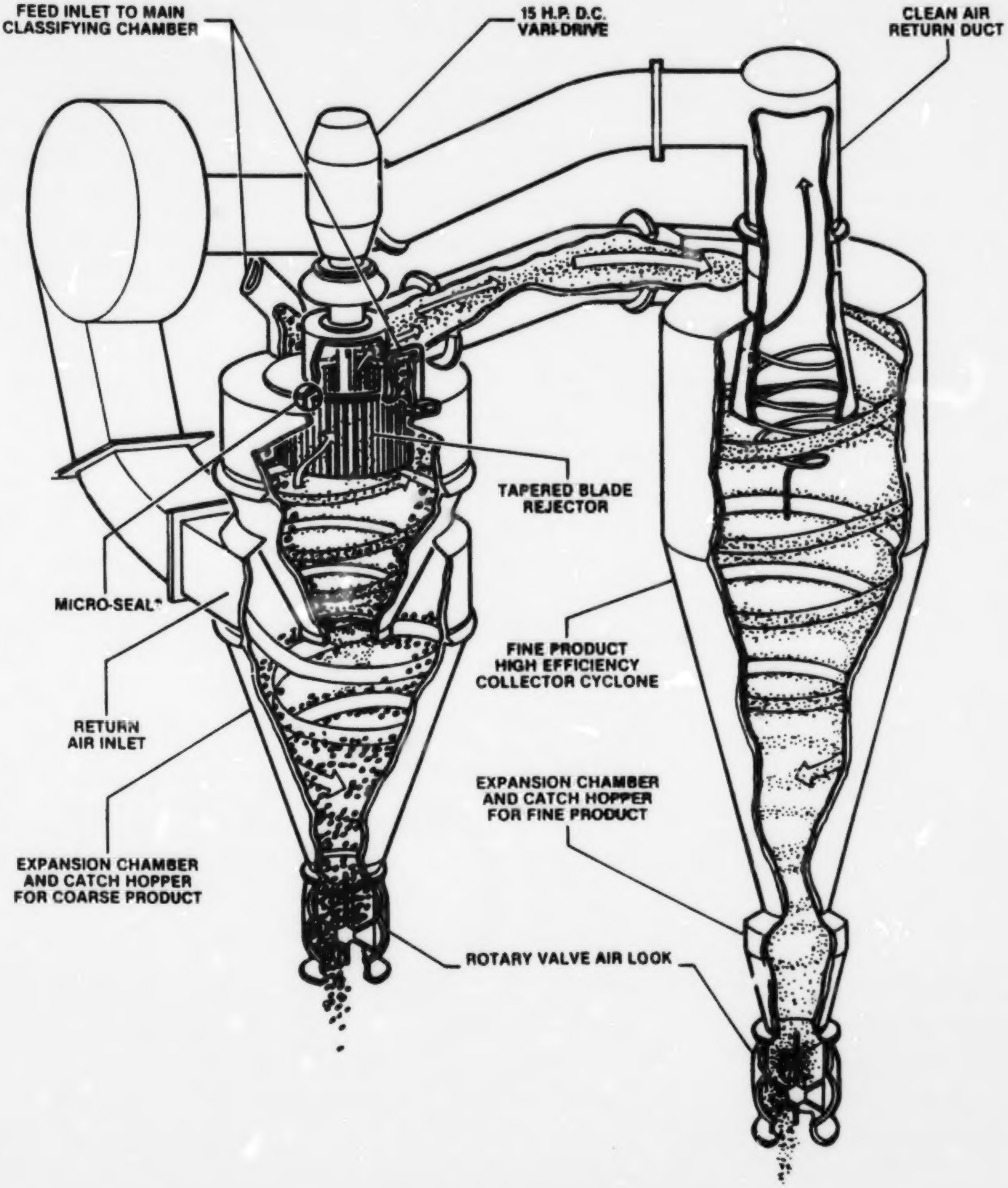
The MS-5 classifier is produced as one of a series of high efficiency air classifiers by Progressive Industries of Sylacagua Alabama.

This company produces the MS-5, 20, 50 & 100 air classifiers. The MS-5 & 20 have found extensive application in the minerals industry, particularly in production of very fine filler products. The MS-50 & 100 air classifiers are recent additions to the product line and are designed to handle larger feed volumes for production of coarser filler products and cements.

The MS series of classifiers belong to the family of forced vortex air classifiers. A schematic of this classifier is shown on Figure 6.3.1-1.

* The use of this particular air classifier is not to be construed as a specific endorsement of this classifier over other available high efficiency air classification equipment.

## The MICROSIZER


FEED INLET TO MAIN CLASSIFYING CHAMBER
15 H.P. D.C. VARI-DRIVE
CLEAN AIR RETURN DUCT
TAPERED BLADE REJECTOR
MICRO-SEAL®
FINE PRODUCT HIGH EFFICIENCY COLLECTOR CYCLONE
RETURN AIR INLET
EXPANSION CHAMBER AND CATCH HOPPER FOR FINE PRODUCT
EXPANSION CHAMBER AND CATCH HOPPER FOR COARSE PRODUCT
ROTARY VALVE AIR LOOK

### 6.3.2 Feed Material for Test with the Microsizer MS-5 Air Classifier

Cement material, used for tests with the MS-5, was provided by Canada Cement Lafarge and consisted of a sample of mill discharge from a tube mill used in the finish grinding of cement, and reject samples from two conventional air separators operating in closed circuit with this grinding mill. These feed materials were supplied from a different plant than feed material used in the O'Sepa, N-20, classification tests.

### 6.3.3 Analysis of Feed Materials

| | Blaine/cm$^2$/g | % -325 Mesh (45 Micron) |
|---|---|---|
| Cement Mill Discharge | 2543 | 57.0 |
| Classifier #4 Rejects | 1852 | 46.0 |
| Classifier #5 Rejects | 1717 | 45.0 |

### 6.3.4 Operating Variables

The controllable operational variables of the MS-5 air classifier are as follows:

- Feed Rate - controlled by variable speed rotary airlock
- Rotor Speed - controlled by variable speed D.C. motor or A.C. variable frequency motor
- Fan Speed - controlled by variable speed D.C. motor or A.C. variable frequency motor

### 6.3.5 Test Objectives

The objective of the tests was to produce a cement product with a Blaine surface area of 3700 (cm$^2$/g) ±100 (cm$^2$/g) and ten (10%) ±2% retained on 325 mesh (45 micron) screen.

Testwork explored the effect of feed rate, rotor and fan speed on classifier efficiency and product quality.

A total of five (5) test series were conducted with the available feed materials.

### 6.3.6 Test Series 1

Test Series 1 used cement mill discharge as feed to the MS-5 air classifier. These tests were conducted at relatively low feed rates.

Test 1, Runs 1 & 2, explored the effect of feed rate, at constant rotor and fan speed on product yield and quality. Runs 3 & 4 explored the effect of feed rate and rotor speed at constant fan speed. Runs 3 & 4 in Test Series 1 essentially were to bring product quality in line with the desired product specification.

Results obtained in Test Series 1 are shown on Table 6.3.5-1.

In all tests, the classifier was operated for up to thirty (30) minutes without feed to allow the system to come to full operating temperature. Each test had a duration of twenty (20) minutes. Sampling was started after five (5) minutes and every three (3) minutes thereafter.

## TABLE 6.3.5-1

### TEST SERIES 1
### MICROSIZER MS-5 AIR CLASSIFIER
### TEST AT LOW FEED RATES

FEED MATERIAL
57% -325 MESH
BLAINE 2543 $cm^2/g$

DISCHARGE FROM CEMENT GRINDING MILL

| RUN NO. | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| FEED RATE (lb/hr) | 806 | 611 | 583 | 522 |
| ROTOR SPEED (rpm) | 725 | 725 | 700 | 675 |
| FAN SPEED (rpm) | 4400 | 4400 | 4400 | 4400 |
| PRODUCT SIZE (%-325 m) | - | - | 90 | 86 |
| REJECT SIZE (%-325 m) | - | - | 6 | 5.18 |
| BLAINE ($cm^2/g$) | 4735 | 4017 | 3809 | 3689 |
| PRODUCT RATE (lb/hr) | 464 | 384 | 390 | 372 |
| RETURN RATE (lb/hr) | 342 | 227 | 193 | 150 |
| REJECTS % | 42.4 | 37.2 | 33.1 | 28.7 |
| PRODUCT % | 57.6 | 62.8 | 66.9 | 71.3 |

COMMENTS

| | |
|---|---|
| Runs 1 & 2 - | Products Finer than Desired |
| Runs 3 & 4 - | Products are close to desired product quality with respect to Blaine surface area and percent passing 325 Mesh. |

### 6.3.7 Test Series 1 - Discussion of Test Results

Results from Test Series 1, Runs 1 & 2, clearly demonstrate the effect of a change in feed rate on product quality and yield, at constant rotor and fan speed.

At the higher (806 lb/hr) feed rate the Blaine surface area of 4735 $cm^2/g$ is well in excess of the 3700 $cm^2/g$ target. By dropping the feed rate to 611 lb/hr, with no change to rotor or fan speed the Blaine surface area was reduced to 4017 $cm^2/g$. Product rate or yield increased from 57.6% to 62.8%.

The effect of feed rate on product quality and yield is quite significant and readily illustrates the necessity for control of feed rates, when other variables such as rotor and fan speed are kept constant. Other test results will show that this effect is more pronounced at low than at high feed rates. This can be explained by the fact that at low feed rates the classifier operates at an efficiency approaching optimum, while at higher feed rates the classifier will be less efficient. At high feed rates, variation in feed rate will not have as pronounced an effect on product quality as at low feed rates.

Test Series 1, Runs 3 & 4, were conducted at lower rotor speeds. Reducing rotor speed, while maintaining constant air flow, results in reduced vortex velocity, allowing coarser particles to escape with the product. This is due to the fact that at constant drag force, but at reduced centrifugal force, particles of apparent greater mass will be affected more by drag forces than by centrifugal force, and become part of the fine fraction that passes through the rotor and out of the classifier.

Results from Test Series 1, Runs 3 & 4, shows that reducing rotor speed by 25 rpm (725 to 700) reduced the Blaine surface area by 200 $cm^2/g$ to 3809. A further reduction in rotor speed to 675 rpm, reduced the Blaine surface area to 3689 $cm^2/g$.

Runs 3 & 4 resulted in acceptable Blaine surface areas. The percentage of material retained on 325 mesh (45 micron) was excellent in Run 3, but too coarse with 14% being retained on 325 mesh (45 micron) screen, in Run 4.

Complete particle size analyses were conducted using the Sedigraph 5000 Particle Size Analyzer. Particle size curves of feed, product and rejects from Test Series 1, Runs 3 & 4 are shown on Figures 6.3.7-1 & 2. A Tromp curve was prepared on a "product" basis to show classifier efficiency at low feed rates. This is shown on figure 6.3.7-3.

The classifier was operated at well below optimum feed rates. The tests essentially demonstrate effect of feed rate and rotor speed on product yield and quality. No calculations of classifier efficiency were made, however, at these feed rates, the classifier operated at almost ninety-nine percent (99%) efficiency.

FIGURE 6.3.7-1

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 1 - RUN 3
(USING MS-5 AIR CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)

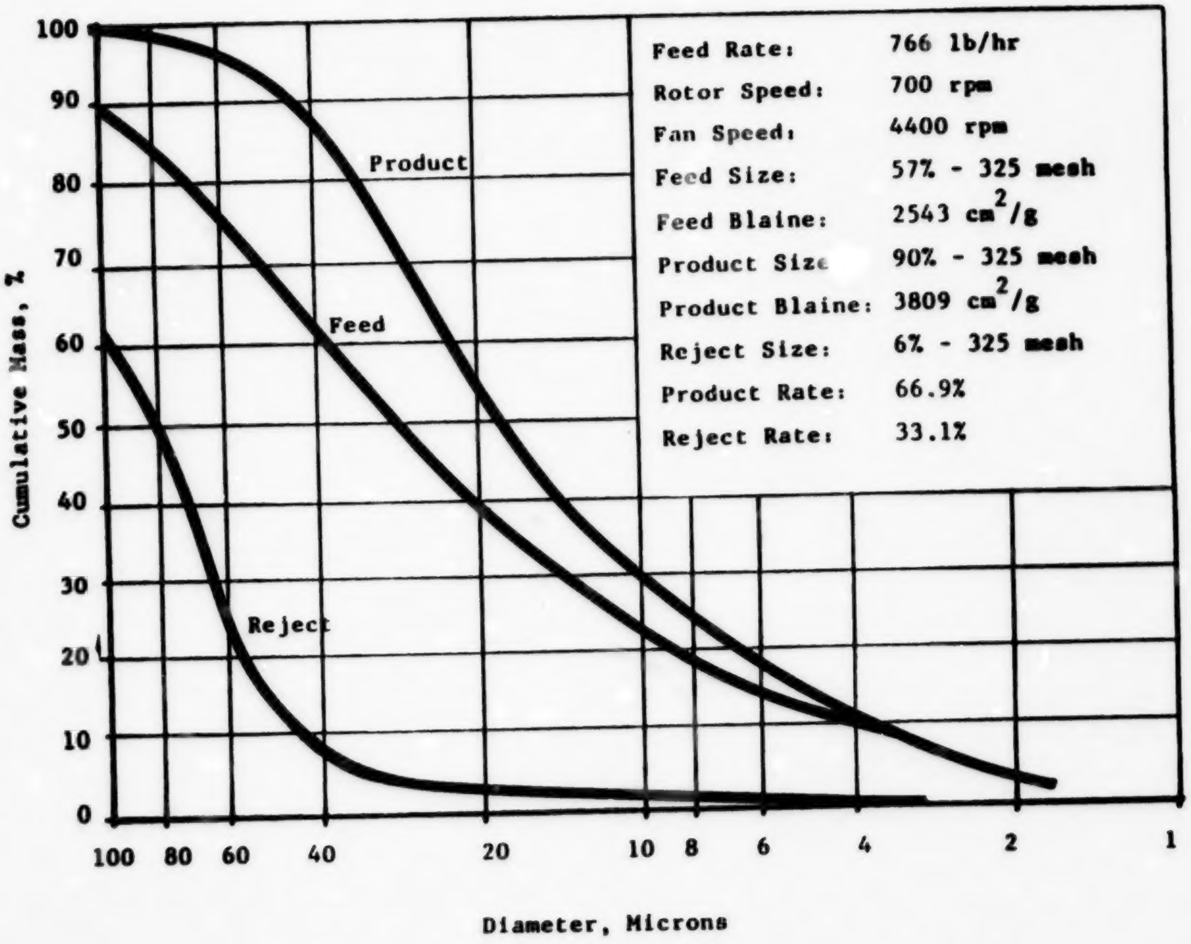
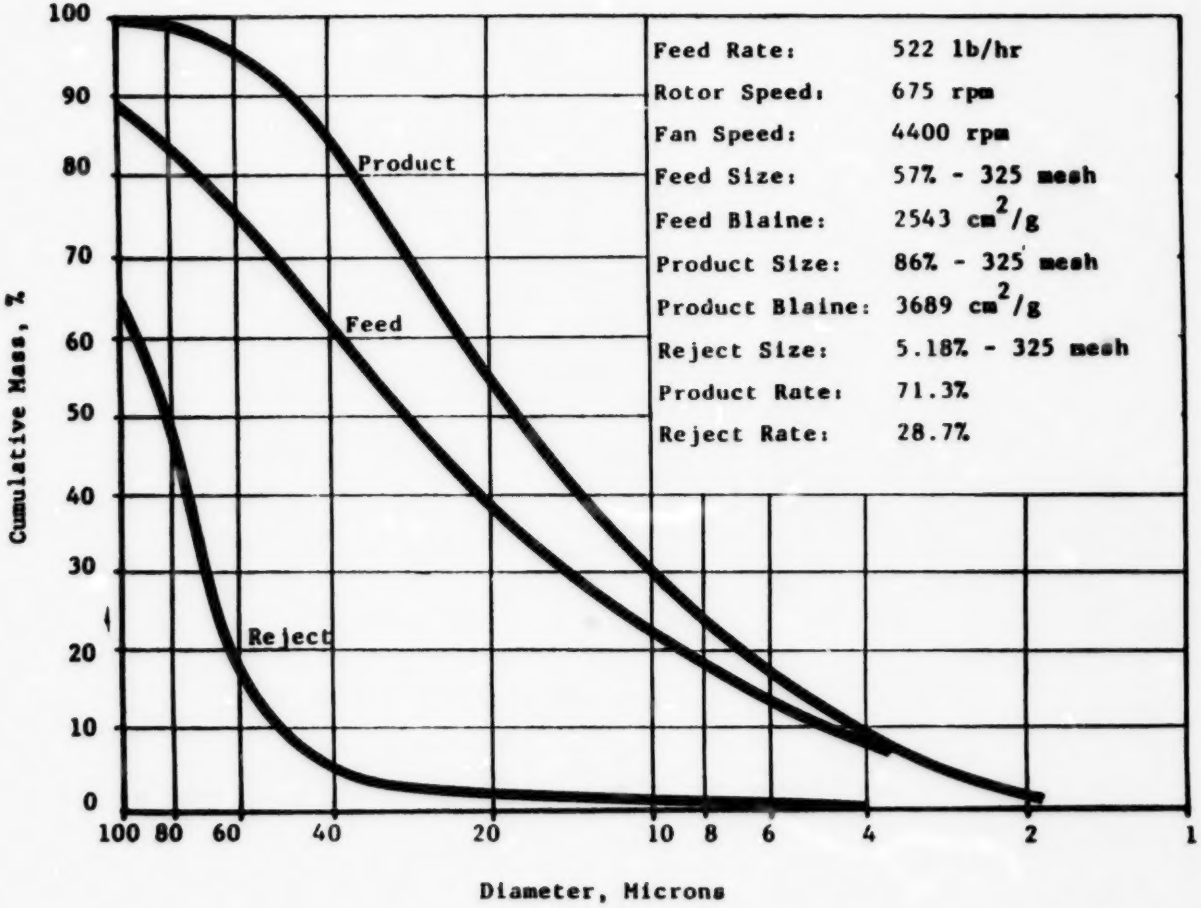


FIGURE 6.3.7-2

PROJECT 5174 - ACTIVITY 2

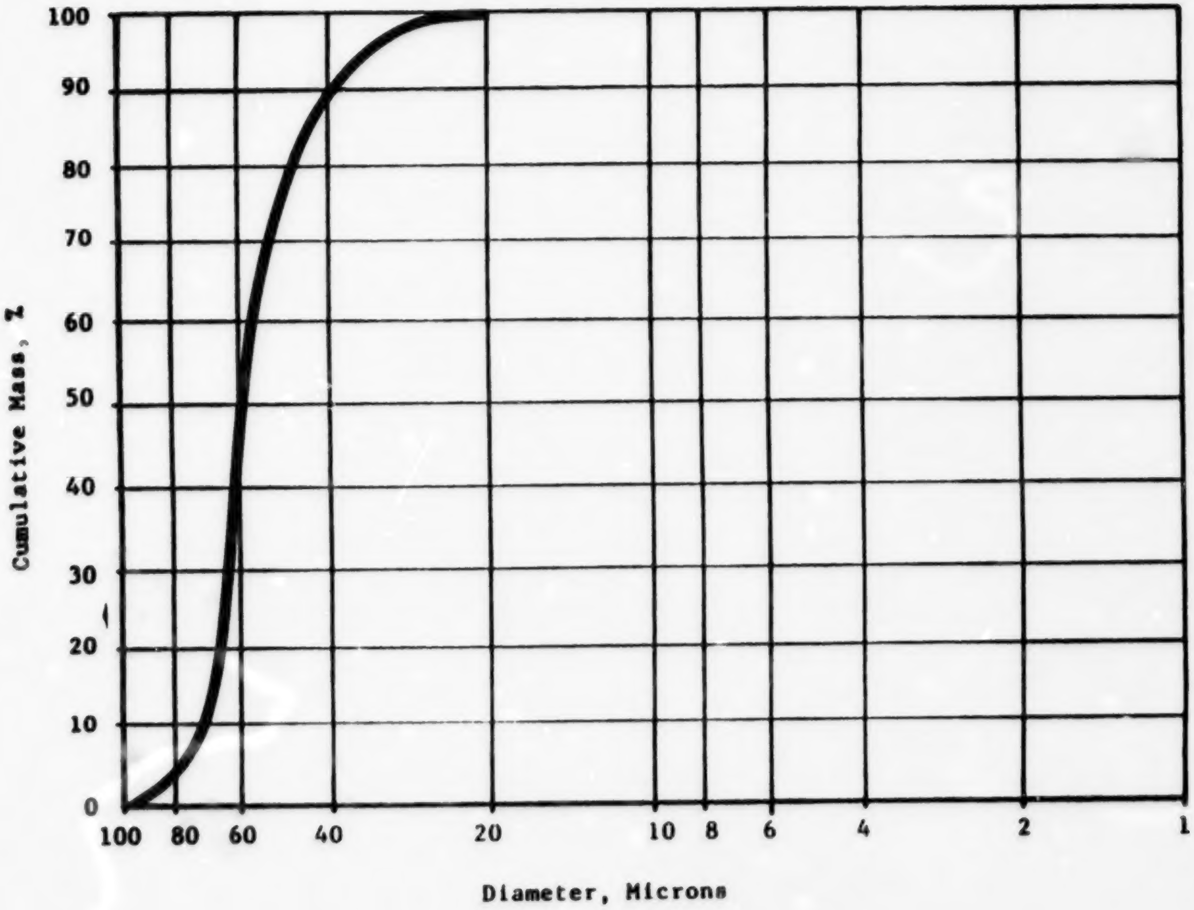
CLASSIFICATION TEST SERIES 1 - RUN 4
(USING MS-5 AIR CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)



## FIGURE 6.3.7-3

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 1 - RUN 3
(USING MS-5 AIR CLASSIFIER AND CEMENT
MILL DISCHARGE AS FEED)
TROMP CURVE - PRODUCT BASIS



### 6.3.8 Test Series 2 - (Tests with MS-5 at lower fan speeds.)

Test Series 2, explored the effect of fan speed on product yield and quality. Reduction of fan speed reduces air velocity and static pressure ( $\Delta$ P) in the classifier. Air volume is reduced, which may result in insufficient air for dispersing and suspending material in the classifying zone. This may lead to "product size" particles dropping out of the classifying zone prematurely.

As in Test Series 1, feed rates were relatively low, so a direct comparison could be made with the tests of higher fan speed in Test Series 1.

Table 6.3.8-1 shows results of three tests made at different fan speeds.

## TABLE 6.3.8-1

## TEST SERIES 2
## MICROSIZER MS-5 AIR CLASSIFIER
## TEST AT LOW FEED RATES AND REDUCED FAN SPEED

FEED MATERIAL — DISCHARGE FROM CEMENT GRINDING MILL

57% -325 Mesh
BLAINE 2543 cm$^2$/g

| RUN NO. | 1 | 2 | 3 |
|---|---|---|---|
| FEED RATE (lb/hr) | 850 | 885 | 674 |
| ROTOR SPEED (rpm) | 725 | 700 | 675 |
| FAN SPEED (rpm) | 3600 | 3900 | 3200 |
| PRODUCT SIZE (%-325 m) | 97 | 93 | 95 |
| REJECT SIZE (%-325 m) | - | - | 23 |
| BLAINE (cm$^2$/g) | 4100 | 3800 | 3782 |
| PROD. RATE (lb/hr) | 445 | 510 | 336 |
| RETURN RATE (lb/hr) | 405 | 375 | 338 |
| REJECTS % | 47.6 | 42.4 | 50.1 |
| PRODUCT % | 52.4 | 57.6 | 49.9 |

### COMMENTS

Tests conducted at lower fan speed resulted in a substantial reduction of product yield, see Table 6.3.5-1.

Product size was finer than the specified product quality. Both percent passing 325 Mesh (45 micron) and Blaine surface area are slightly higher than desired.

### CONCLUSION

Reduction of fan speed below 3900 rpm results in a significant drop in classifier efficiency.

### 6.3.9 Discussion of Test Results - Test Series 2

The reduction in fan speed had a significant effect on classifier efficiency and production rate. Production rate dropped from 57.6% at a fan speed of 3900 rpm to 49.9% at a fan speed of 3200 rpm.

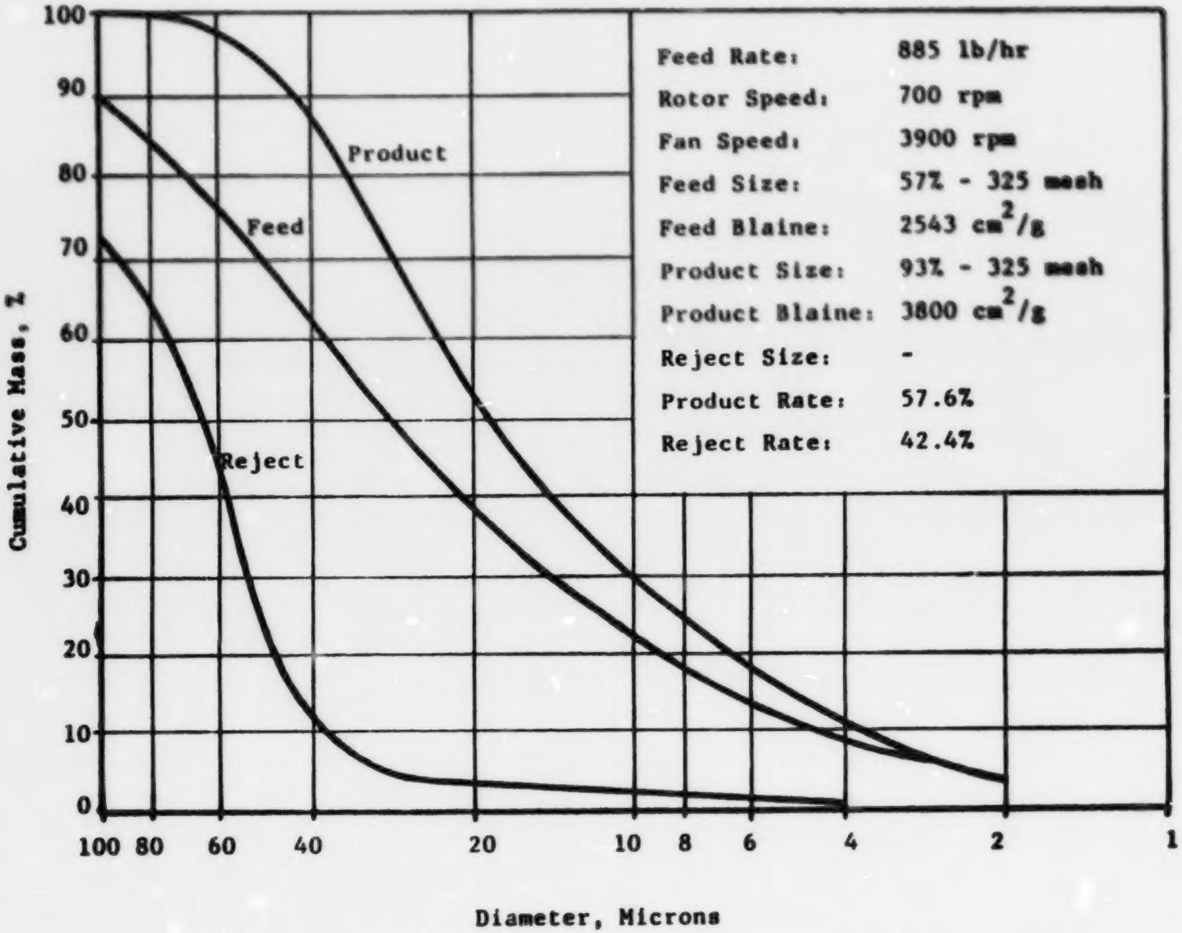
The desired product quality with respect to Blaine surface area or percent retained on 325 mesh (45 micron) were readily achieved. But as noted, productivity diminished at lower fan speed. Comparing these tests with Runs 3 & 4 from Test Series 1, product yield dropped from a high of 66.9% in Test Series 1 Run 3 at a fan speed of 4400 rpm to a low of 49.9% in Run 3, Test Series 2 at a fan speed of 3200 rpm. This illustrates that classifier performance and efficiency is influenced by both feed rate and fan speed.

Particle size distributions were determined on feed, classifier products and rejects of Test 2, Runs 2 & 3, using the Sedigraph 5000 Particle Size Analyzer. Results of these analysis are shown on Figures 6.3.9-1 and 6.3.9-2.

## FIGURE 6.3.9-1

PROJECT 5174 - ACTIVITY 2

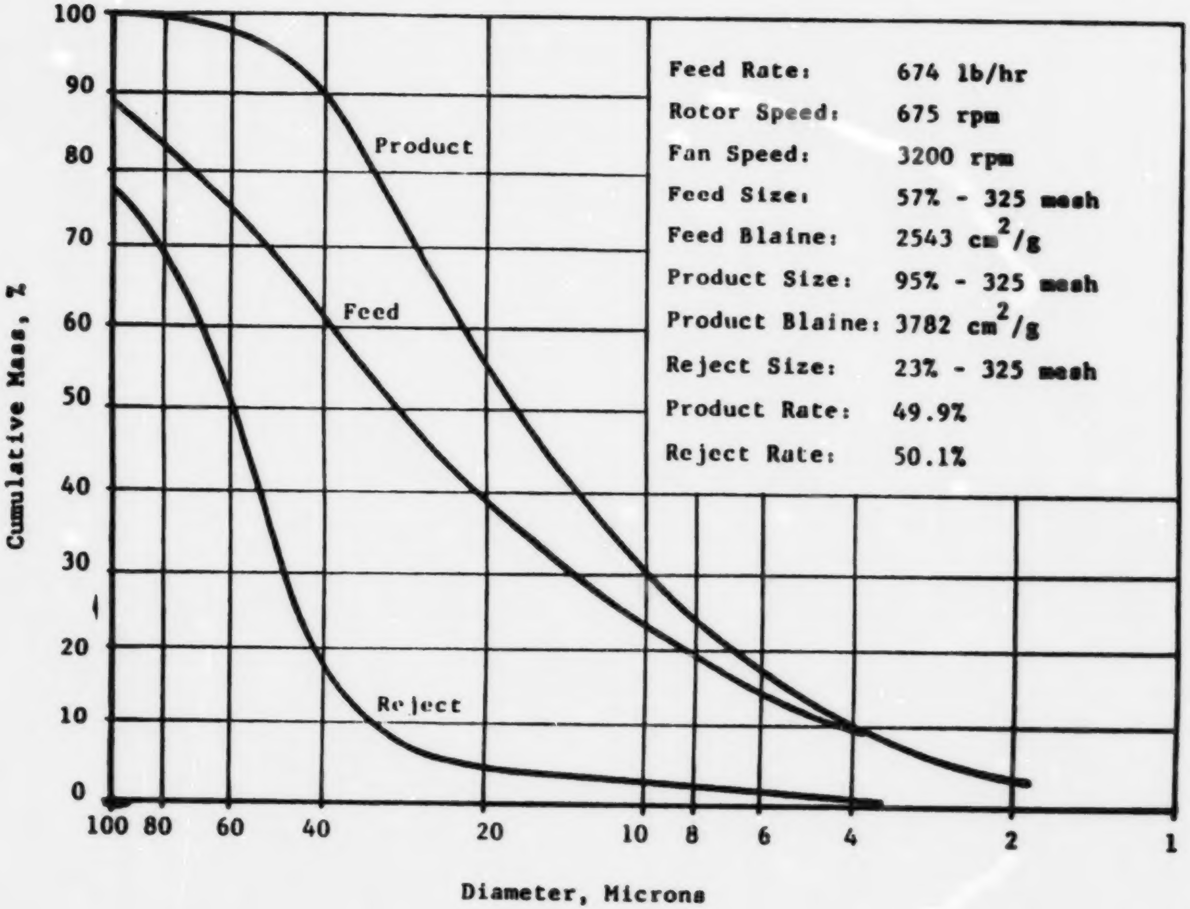
CLASSIFICATION TEST SERIES 3 - RUN 2
(USING MS-5 AIR CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)



## FIGURE 6.3.9-2

## PROJECT 5174 - ACTIVITY 2

### CLASSIFICATION TEST SERIES 3 - RUN 3
### (USING MS-5 AIR CLASSIFIER AND CEMENT MILL DISCHARGE AS FEED)



| | |
|---|---|
| Feed Rate: | 674 lb/hr |
| Rotor Speed: | 675 rpm |
| Fan Speed: | 3200 rpm |
| Feed Size: | 57% - 325 mesh |
| Feed Blaine: | 2543 $cm^2/g$ |
| Product Size: | 95% - 325 mesh |
| Product Blaine: | 3782 $cm^2/g$ |
| Reject Size: | 23% - 325 mesh |
| Product Rate: | 49.9% |
| Reject Rate: | 50.1% |

### 6.3.10 Test Series #3

Tests at high feed rates and constant fan speed.

Test Series 3 was conducted at high feed rates and a constant 4400 rpm fan speed. The purpose of this test was to show the effect of rotor speed (rpm) at high feed rates on product yield and quality.

Feed rates, as employed in this test series, are close to the maximum practical feed rate for a MS-5 air classifier, without significant reduction in classifier efficiency. The primary objective of air classification is to extract the maximum amount of acceptable product and to return clean, "product free" rejects to the grinding mill.

Test Series 3, consisted of five (5) individual runs at feed rates of 2000 lb/hr with fan speed controlled at 4400 rpm during all tests. Main process variables are higher feed rates and variations in rotor speed.

Table 6.3.10-1 shows results obtained in Test Series 3. Sedigraph 5000 Particle Size Analyser curves of feed, products and rejects for runs 2, 3 and 4 shown on Figures 6.3.10-2, 3 and 4.

## TABLE 6.3.10-1

## MICROSIZER MS-5 CLASSIFICATION TESTS
## CEMENT CLASSIFICATION AT HIGH FEED RATES
## TEST SERIES 3

FEED MATERIAL — CEMENT MILL DISCHARGE

57% -325

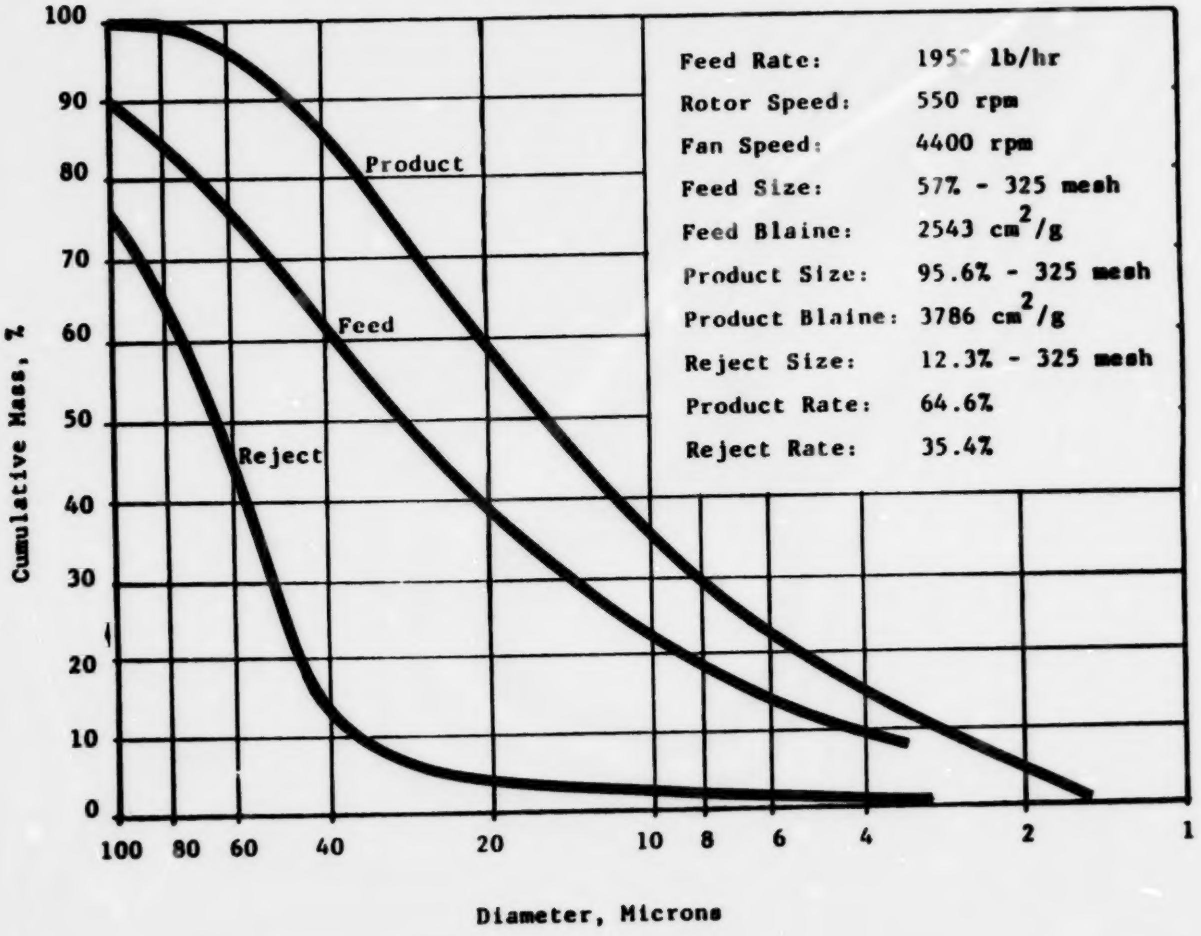
BLAINE 2543 $cm^2/g$

| RUN NO. | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| FEED RATE (lb/hr) | 1952 | 1760 | 1847 | 2080 |
| ROTOR SPEED (rpm) | 550 | 600 | 650 | 500 |
| FAN SPEED (rpm) | 4400 | 4400 | 4400 | 4400 |
| PRODUCT SIZE (%-325 m) | 95.6 | 97.3 | 98.7 | 90.1 |
| REJECT SIZE (%-325 m) | 12.3 | 16.6 | 15.2 | 10.7 |
| BLAINE ($cm^2/g$) | 3786 | 3719 | 4097 | 3362 |
| PRODUCT RATE (lb/hr) | 1260 | 1085 | 980 | 1496 |
| RETURN RATE (lb/hr) | 692 | 675 | 867 | 584 |
| REJECTS % | 35.4 | 38.4 | 46.9 | 28.1 |
| PRODUCT % | 64.6 | 61.6 | 53.1 | 71.9 |

FIGURE 6.3.10-2

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 3 - RUN 2
(USING MS-5 AIR CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)

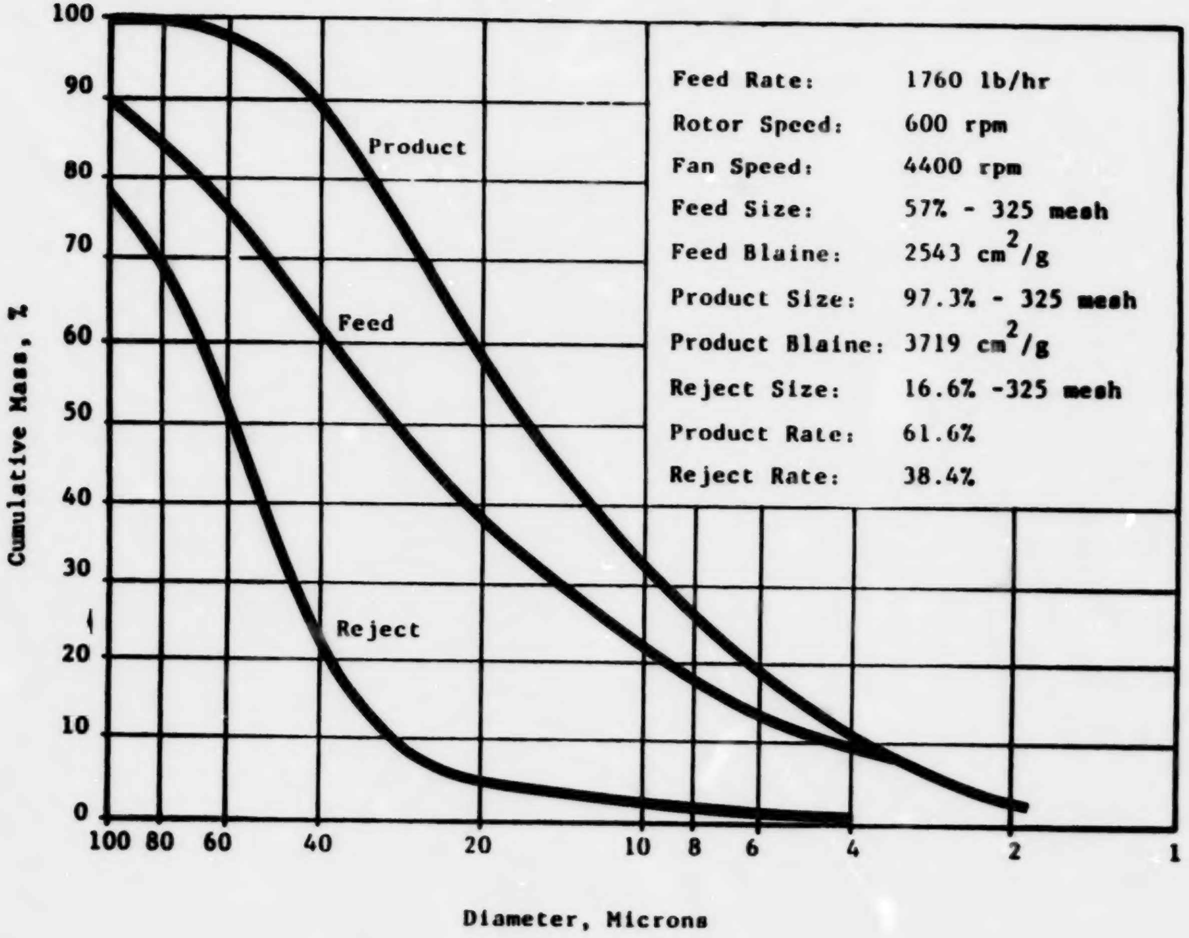


Feed Rate: 1950 lb/hr
Rotor Speed: 550 rpm
Fan Speed: 4400 rpm
Feed Size: 57% - 325 mesh
Feed Blaine: 2543 $cm^2/g$
Product Size: 95.6% - 325 mesh
Product Blaine: 3786 $cm^2/g$
Reject Size: 12.3% - 325 mesh
Product Rate: 64.6%
Reject Rate: 35.4%

FIGURE 6.3.10-3

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 3 - RUN 3
(USING MS-5 AIR CLASSIFIER AND CEMENT
MILL DISCHARGE AS FEED)

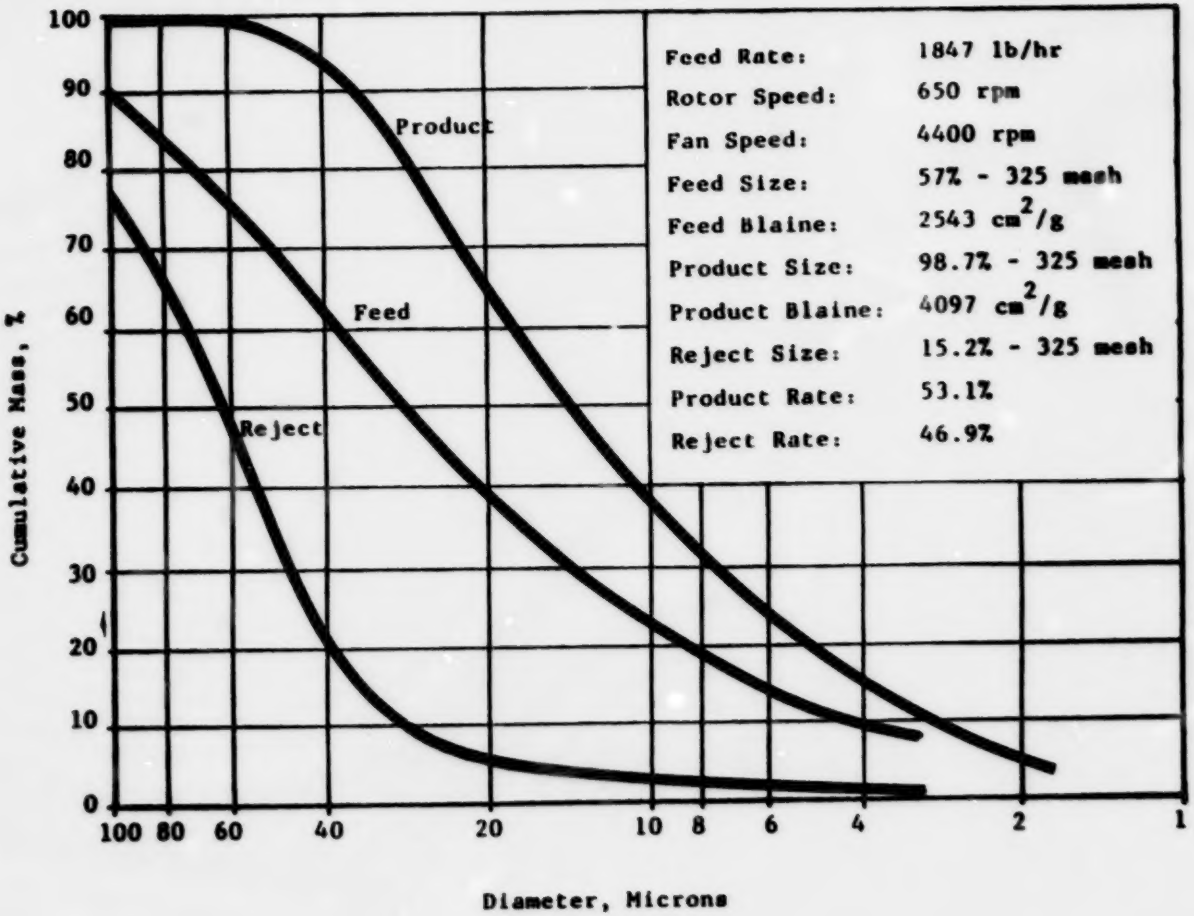


Feed Rate: 1760 lb/hr
Rotor Speed: 600 rpm
Fan Speed: 4400 rpm
Feed Size: 57% - 325 mesh
Feed Blaine: 2543 $cm^2/g$
Product Size: 97.3% - 325 mesh
Product Blaine: 3719 $cm^2/g$
Reject Size: 16.6% -325 mesh
Product Rate: 61.6%
Reject Rate: 38.4%

## FIGURE 6.3.10-4

### PROJECT - 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 3 - RUN 4
(USING MS-5 AIR CLASSIFIER AND CEMENT MILL
DISCHARGE AS FEED)



| | |
|---|---|
| Feed Rate: | 1847 lb/hr |
| Rotor Speed: | 650 rpm |
| Fan Speed: | 4400 rpm |
| Feed Size: | 57% - 325 mesh |
| Feed Blaine: | 2543 $cm^2/g$ |
| Product Size: | 98.7% - 325 mesh |
| Product Blaine: | 4097 $cm^2/g$ |
| Reject Size: | 15.2% - 325 mesh |
| Product Rate: | 53.1% |
| Reject Rate: | 46.9% |

### 6.3.11 Discussion of Results Test Series #3

Test Series 3, Runs 2, 3, 4 and 5, were made at feed rates approaching 2000 lb/hr. The only operating variable in the series was classifier rotor speed.

As is shown by results, the rotor speed required to achieve acceptable Blaine surface area is significantly lower than with tests at low feed rates. This can be explained by the fact that as grain loading, i.e., percentage of solids in the air, increases more of the fan energy is consumed in dispersing, suspending and accelerating the solids. This results in reduced particle velocity, and therefore lower drag forces in the classification zone. Thus, less centrifugal force is required to overcome air/particle velocity, which allows the required particle separation to be made at lower rotor speed.

In addition to lower air particle velocity, it is also possible for finer particles to be physically displaced, i.e., moved out of their proper trajectory, by particle to particle collisions near the outside of the vortex away from the rotor and to subsequently drop out with the coarse particles. This results in rejects containing high amounts of (potential) product, and a corresponding drop in classifier efficiency.

Feed rates can be taken to such an extreme that there is no longer any separation. Under such conditions rejects produced during classification have virtually the same particle size as the feed to the classifier.

It is important to determine the most ideal air/solids ratio or grain loading for optimum classification efficiency. This ratio will vary with each type of feed particle size distribution, fineness of product desired and density of feed material. If air flow is constant, obviously the only method for achieving proper air to solids ratio is by control of the feed rate. Another important factor in this equation is air density. Air density is affected by temperature and/or elevation. At lower air density the ability of air to disperse, suspend and accelerate the particles is reduced. A similar effect occurs at high elevation. This can be compensated (to some extent) by increasing fan speed or fan size.

For testing purposes it is mandatory that testing of a classifier be conducted at the temperature expected in the actual plant environment.

Results from Test Series 3, Runs 2 & 3 show that the required Blaine surface area was readily achieved, however, the requirement for ninety percent (90%) passing a 325 mesh (45 micron) screen was not met. In Run 5 this objective was realized but at a much lower Blaine surface area. The lower percentage retained on 325 mesh (45 micron) screen (at the required Blaine surface area) is indicative of a steeper particle size curve.

Classifier efficiency was calculated for Runs 2 & 3, which gave results as shown in Table 6.3.11-1.

## TABLE 6.3.11-1

## TEST SERIES 3, RUNS 2 & 3

### CALCULATION OF CLASSIFIER EFFICIENCY AT 40, 20 & 10 MICRON BASED ON SEDIGRAPH ANALYSES OF CLASSIFIER FEED, PRODUCT AND REJECTS

| | Run 2 | | | Run 3 | | |
|---|---|---|---|---|---|---|
| Microns | 40 | 20 | 10 | 40 | 20 | 10 |
| Calculated % Product Yield | 67.0 | 63 | 63.6 | 62.7 | 62.2 | 66.6 |
| Calculated % Oversize | 33 | 37 | 36.4 | 37.3 | 37.8 | 33.4 |
| Calculated Classifier Eff. Prod. Basis % | 92.9 | 96.1 | 96.7 | 90.0 | 94.9 | 95.6 |
| Ratio: Tons of Feed/ Ton of Product | 1.48 | 1.58 | 1.57 | 1.59 | 1.60 | 1.50 |
| % Circulating Load | 48 | 58 | 57 | 59 | 60 | 50 |
| Actual Measured Product Yield in % | 64.6 | | | 61.6 | | |
| Actual Measured Oversize Yield in % | 35.4 | | | 38.4 | | |

Comments: Classification efficiency is excellent. Calculated product yield (based on sedigraph analysis) compares well with actual observed production rates.

## 6.4 Tests on Rejects From Conventional Air Classifier

To demonstrate how high efficiency classification can be employed as a second stage of classification, tests were conducted using rejects (coarse fraction) from a conventional classifier installed in a cement grinding-classification circuit. The tests intend to show the potential of two stage classification.

The purpose of the tests was to determine the amount of product with appropriate Blaine surface area and percent retained on 325 mesh (45 micron) screen that can be extracted from this particular quality of reject material.

Reject material was obtained from an operating cement grinding plant with the process in balance. Rejects were taken from two conventional air separators.

Tests were conducted with the Progressive Industries MS-5 high efficiency air classifier.

The feed materials had the following analysis:

| | Blaine $cm^2/g$ | % -325 mesh (45 micron) |
|---|---|---|
| Rejects #4 classifier | 1852 | 46 |
| Rejects #5 classifier | 1717 | 45 |

Two test series, #4 and #5 were conducted. The first series, consisting of two runs were at low feed rates. The second series of three runs was at high feed rates.

The objective of these tests were to achieve products with a Blaine surface area of 3700 $cm^2/g$ ± 100 $cm^2/g$.

### 6.4.1 Test Series #4

Test Series #4 used reject material from #4 air separator as feed material for tests with the MS-5 air classifier. Based on results achieved on the classification of cement mill discharge the following classifier operating parameters were selected for this test series.

Fan Speed: 4400 rpm.
Feed Rate: 700 lb/hr.
Rotor Speed: Run 1, 700 rpm. Run 2, 725 rpm.

Tests were conducted with the system at normal operating temperature. The classifier was operated at the required feed rate for fifteen (15) minutes, at which time the product and reject stream were sampled for five (5) minutes.

Products as produced during Test Series 4, Runs 1 & 2 were analyzed using a Sedigraph 5000 Particle Size Analyser. Detailed test results are shown on Table 6.4.1-1. Completed Sedigraph size distributions of feed, product and rejects of Run 2 are shown on Figure 6.4.1-2.

## TABLE 6.4.1-1

### TEST 4

### MICROSIZER MS-5 AIR CLASSIFIER
### TEST AT LOW FEED RATES

| FEED MATERIAL | #5 SEPARATOR OVERSIZE |
|---|---|
| % -325 (45 micron) | 45 |
| BLAINE $cm^2/g$ | 1717 |

| RUN NO. | 1 | 2 |
|---|---|---|
| FEED RATE (lb/hr) | 727 | 699 |
| ROTOR SPEED (rpm) | 700 | 725 |
| FAN SPEED (rpm) | 4400 | 4400 |
| PRODUCT SIZE (% -325 m) | - | 92 |
| REJECT SIZE (% -325 m) | - | 4 |
| BLAINE ($cm^2/g$) | | 3629 |
| PRODUCT RATE (lb/hr) | 390 | 392 |
| RETURN RATE (lb/hr) | 337 | 307 |
| REJECTS % | 46.4 | 43.9 |
| PRODUCT % | 53.6 | 56.1 |

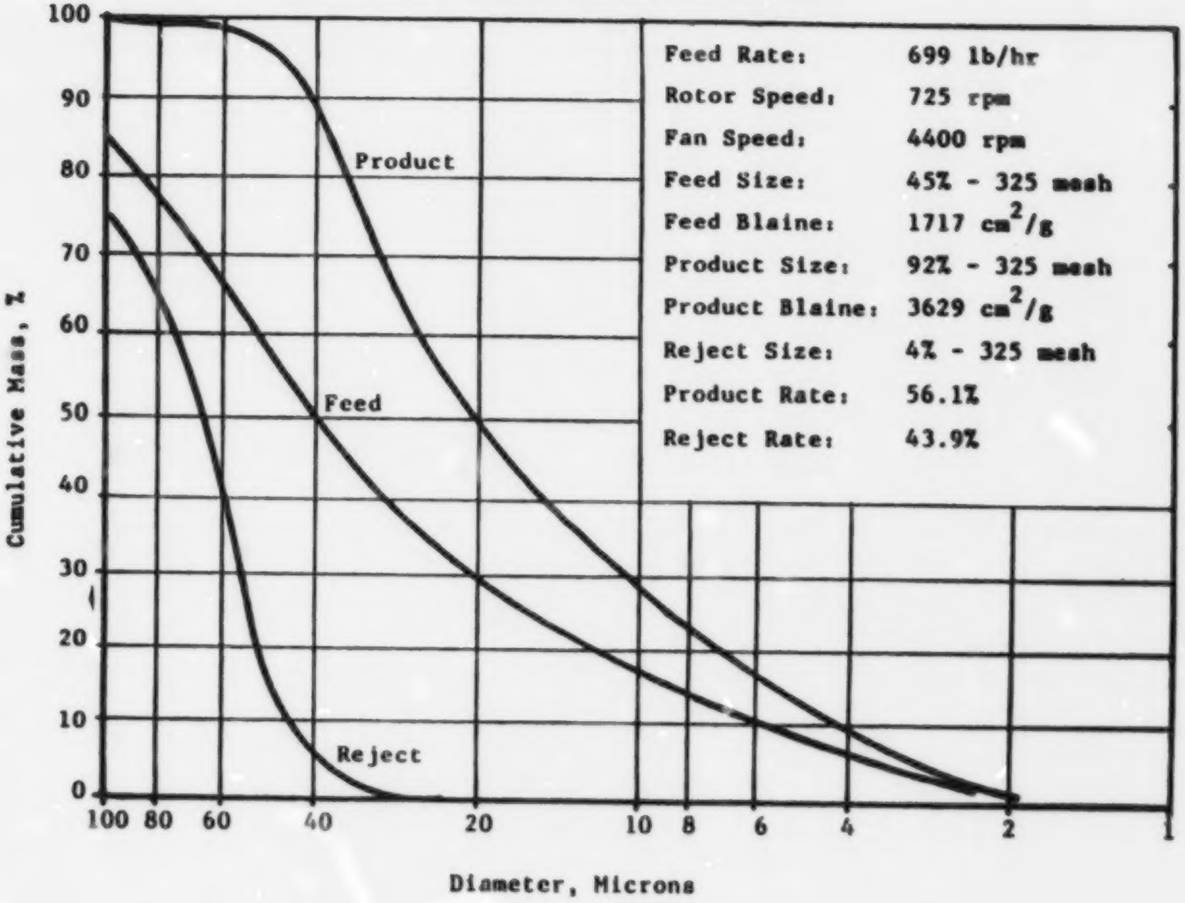
COMMENTS

A significant amount of acceptable cement product was extracted from the rejects. Classification efficiency was excellent at this low feed rate. This is shown on Table 6.4.1-3.

## FIGURE 6.4.1-2

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 4 - RUN 2
(USING MS-5 AIR CLASSIFIER AND REJECT FROM
CONVENTIONAL CEMENT CLASSIFIER AS FEED)



## TABLE 6.4.1-3

## TEST SERIES 4 - RUN 2

## CALCULATED PRODUCT RECOVERY AND CLASSIFIER EFFICIENCY AT 40, 20 & 10 MICRONS
(BASED ON SEDIGRAPH ANALYSIS)

| | Run 2 | | |
|---|---|---|---|
| Micron Size | 40 | 20 | 10 |
| Calculated % Product Yield | 54.3 | | |
| Calculated % Oversize | 45.7 | | |
| Calculated Classifier Efficiency - Product Basis % | 94.5 | 100.0 | 100.0 |
| Ratio: Tons Feed/Ton of Product | 1.84 | 1.69 | 1.65 |
| % Circulating Load | 84 | 69 | 65 |
| Actual Measured Product Yield - % | 56.1 | | |
| Actual Measured Oversize Yield - % | 43.9 | | |

### 6.4.2 Discussion of Test Results

Calculated results for recovery agree substantially with (actual) measured recovery. Classifier efficiency is exceptional at this low feed rate.

Rejects (oversize) produced was very coarse and essentially free of any "product size" material.

It must be stressed, that the feed rate used for these tests, is well below the design capacity of the classifier. Test Series 5 at a 2,500 lb/hr feed rate provides a more realistic assessment of the capacity of the "pilot plant" sized air classifier.

### 6.5 Test Series 5, Runs 1, 2 & 3

In Test Series 5, a higher feed rate was used. Feed material was rejects from the #4 air classifier with a Blaine surface area of 1,852 $cm^2/g$ and forty-six (46%) passing 325 mesh (45 micron) screen.

All operating conditions were kept constant, except rotor speed. The intended feed rate was 2,500 lb/hr. In Run 1, the actual feed rate was 2,295 lb/hr. In Runs 2 & 3 the feed rates were close to the intended rate, at 2,452 and 2,507 lb/hr respectively.

Table 6.5-1 shows actual test conditions, product yield and product analysis. Figures 6.5.2, 3 and 4 show Sedigraph size distributions of feed, product and rejects.

## TABLE 6.5-1

### MS-5 CLASSIFICATION TESTS
### CEMENT CLASSIFICATION AT HIGH FEED RATES
### TEST SERIES 5

**FEED MATERIAL** REJECTS FROM CONVENTIONAL AIR CLASSIFIER

46% -325

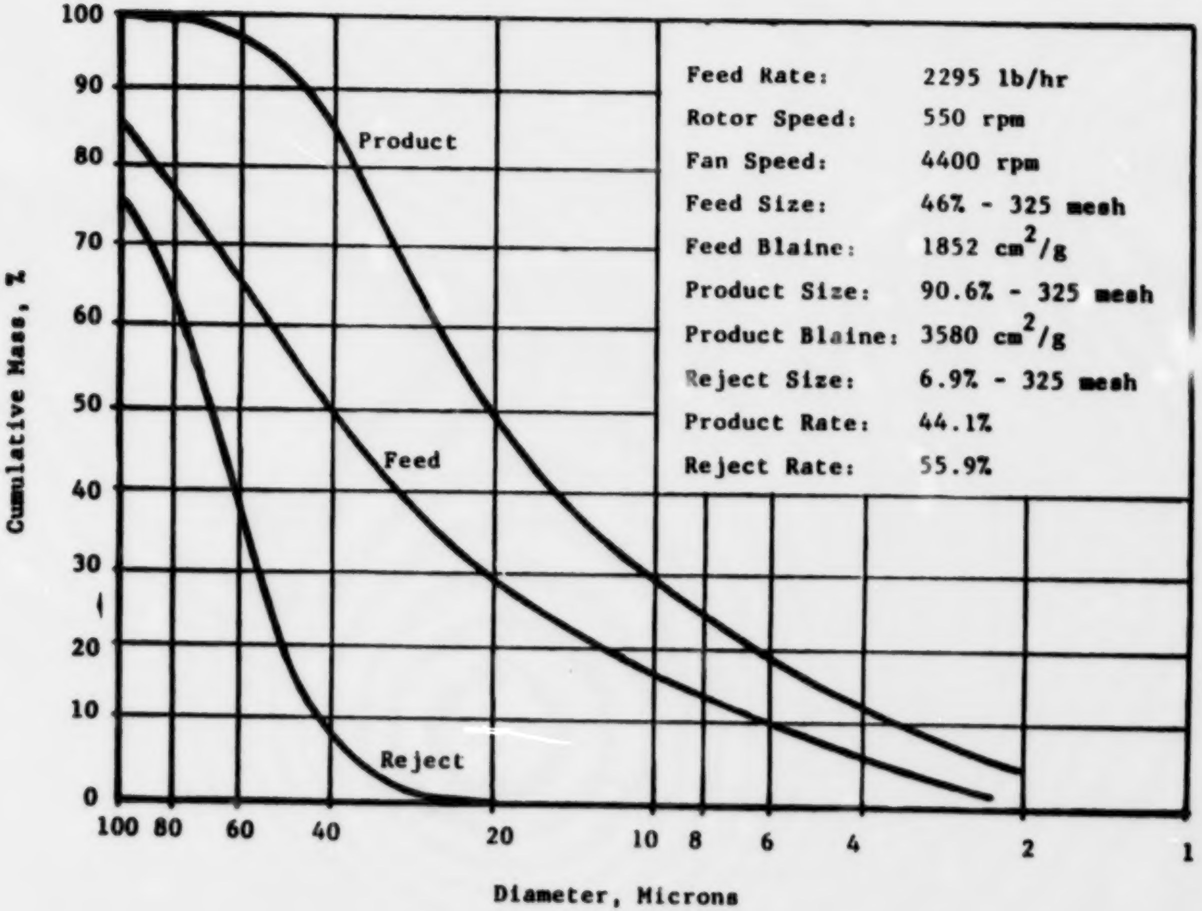
Blaine 1,852 cm$^2$/g

| RUN NO. | 1 | 2 | 3 |
|---|---|---|---|
| FEED RATE (lb/hr) | 2295 | 2452 | 2507 |
| ROTOR SPEED (rpm) | 550 | 600 | 650 |
| FAN SPEED (rpm) | 4400 | 4400 | 4400 |
| PRODUCT SIZE (% -325 m) | 90.6 | 97.0 | 98.4 |
| REJECT SIZE (% -325 m) | 6.9 | 12.4 | 13.8 |
| BLAINE (cm$^2$/g) | 3580 | 3753 | 3865 |
| PRODUCT RATE (lb/hr) | 1013 | 960 | 951 |
| RETURN RATE (lb/hr) | 1282 | 1492 | 1557 |
| REJECTS % | 55.9 | 60.8 | 62.1 |
| PRODUCT % | 44.1 | 39.2 | 37.9 |

## FIGURE 6.5-2

**PROJECT 5174 - ACTIVITY 2**

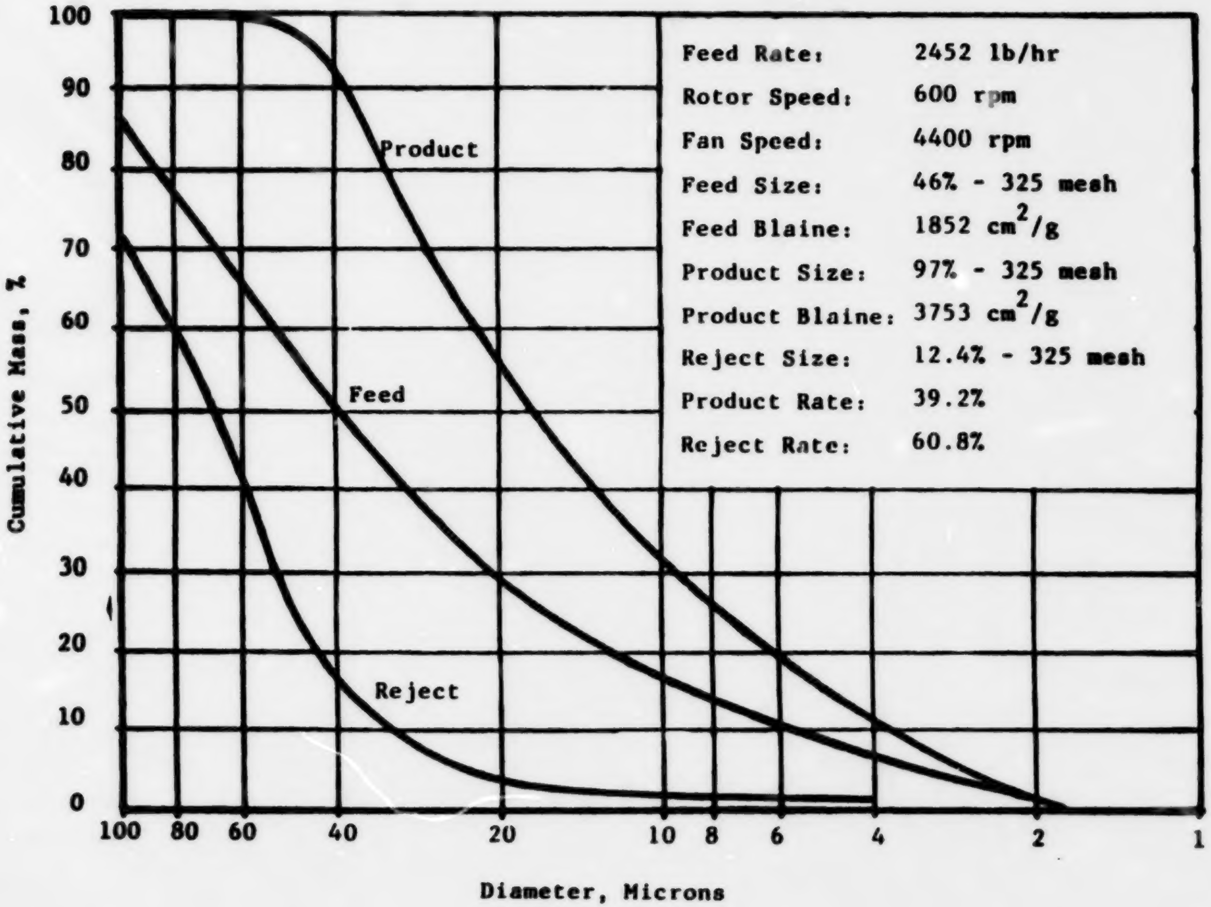
CLASSIFICATION TEST SERIES 5 - RUN 1
(USING MS-5 AIR CLASSIFIER AND REJECT FROM
CONVENTIONAL CEMENT CLASSIFIER AS FEED)



## FIGURE 6.5-3

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 5 - RUN 2
(USING MS-5 AIR CLASSIFIER AND REJECT FROM
CONVENTIONAL CEMENT CLASSIFIER AS FEED)

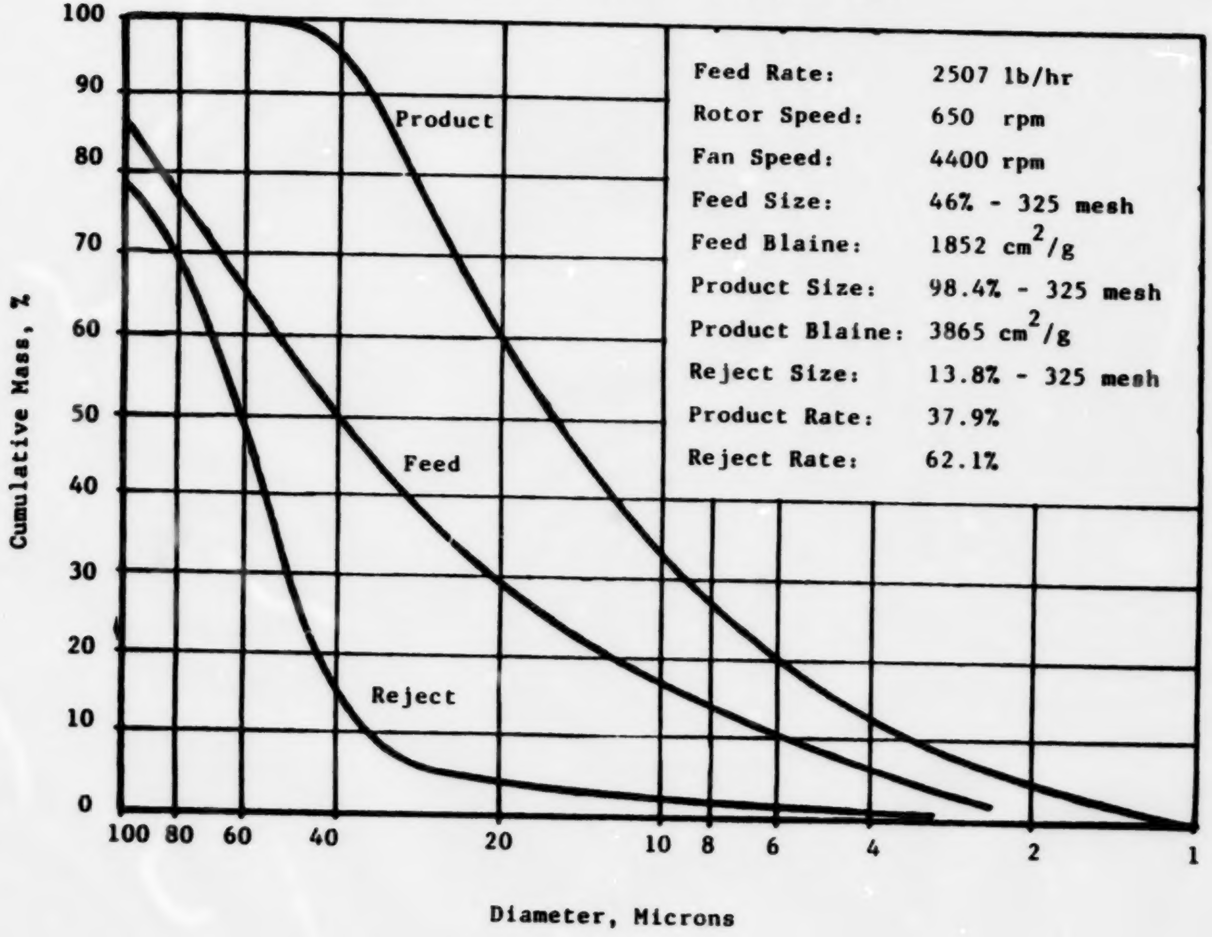


Feed Rate: 2452 lb/hr
Rotor Speed: 600 rpm
Fan Speed: 4400 rpm
Feed Size: 46% - 325 mesh
Feed Blaine: 1852 $cm^2/g$
Product Size: 97% - 325 mesh
Product Blaine: 3753 $cm^2/g$
Reject Size: 12.4% - 325 mesh
Product Rate: 39.2%
Reject Rate: 60.8%

FIGURE 6.5-4

PROJECT 5174 - ACTIVITY 2

CLASSIFICATION TEST SERIES 5 - RUN 3
(USING MS-5 AIR CLASSIFIER AND REJECT FROM
CONVENTIONAL CEMENT CLASSIFIER AS FEED)



### 6.5.1 Discussion of Test Series 5

Test Series 5, is a more realistic evaluation of the benefits that can be expected from two stage air classification. The high efficiency air classifier for the second stage of the classification.

All three test runs gave Blaine results reasonably close to the target value of 3,700 $cm^2/g$. Feed rates were roughly equal for all tests and fan speed was contant. The only variable was rotor speed. As indicated, rotor speed has a significant influence on product quality, with all other operating variables kept constant.

Run 1 succeeded in achieving the objective of ten (10) percent being retained on 325 mesh (45 micron) screen, but with a Blaine of only 3,[illegible]80 $cm^2/g$. Runs 2 & 3 resulted in products with significantly lower amounts being retained on 325 mesh (45 micron) screen, i.e. 3.0% and 1.6% respectively. Run 2 achieved the desired Blaine of 3,753 $cm^2/g$, while product from Run 3 had a Blaine of 3,865 $cm^2/g$. Product recovery ranged from 37.9% to 44.1%.

Rejects produced were quite clean, with only 6.9% to 13.8% passing 325 mesh (45 micron) screen.

Calculated classifier efficiency achieved in Test 5, Run #2, is shown on Table 6.5.1-1.

## TABLE 6.5.1-1

## TEST SERIES 5, RUN 2

## CALCULATED PRODUCT RECOVERY AND CLASSIFIER EFFICIENCY AT 40, 20 & 10 MICRONS

(BASED ON SEDIGRAPH ANALYSIS)

| | Run 2 | | |
|---|---|---|---|
| Micron Size | 40 | 20 | 10 |
| Calculated % Product Yield | 44.7 | | |
| Calculated % Oversize | 55.3 | | |
| Calculated Classifier Efficiency - Product Basis % | 80.6 | 90.0 | 93.0 |
| Ratio: Tons Feed/Ton of Product | 2.23 | 2.16 | 2.14 |
| % Circulating Load | 123 | 116 | 114 |
| Actual Measured Product Yield - % | 39.2 | | |
| Actual Measured Oversize Yield - % | 60.8 | | |

There is a discrepancy between calculated and actual measured product yield. This may be caused by an error in Sedigraph analysis. However, classifier efficiency is excellent at this feed rate.

### 6.5.2 Comments on Test Series 5

Results achieved in Test Series 5, unequivocally prove the benefit and potential of the "two stage" classification concept. This is particularly true, if the first stage of classification is with a conventional air classifier.

For any type or kind of high efficiency air classification equipment the most critical factor is to maintain constant feed rate and feed quality. Classifier efficiency is very much a function of feed rate. Invariably classification efficiency drops off as feed rate increases. Reduced classification efficiency results in loss of productivity and also has a negative influence on the grinding process. It must be emphasized that good classification can improve the efficiency of the grinding process, whereas effective grinding cannot improve air classification.

Another factor not to be overlooked, is the fact that high efficiency classifiers are very flexible. Changes in product quality or type can be very quickly made, usually with a simple change of rotor speed. This facilitates changing to a different type of cement without making extensive changes. Normally, a change in rotor speed will be the only classifier change required.

Changes in mill feed rates are required when changing to a product with a significantly different particle size distribution and/or surface area. Maintaining product quality during transition from one product to another, is often difficult as it will require time for the mill to reach its new "steady state" condition.

## 7.0 SINGLE STAGE OR TWO STAGE CLASSIFICATION

As discussed in sections 6.2 and 6.4, rejects from a conventional classifier were reclassified with a high efficiency air classifier under pilot plant conditions. These tests showed conclusively that significant amounts of product with appropriate Blaine surface area, can be extracted from rejects (oversize) produced by a conventional classifier.

The practical application of two stage air classification, to a large extent, depends on specific conditions existing in a cement grinding plant.

Considerations with regards to space availability, materials handling equipment etc. are important factors influencing a decision whether to replace an existing, conventional air separator with a "state of the art" high efficiency air classifier, or to install a second (smaller) high efficiency air classifier as a "second stage" classifier.

Prior to making such a decision, it is necessary to evaluate the benefits that can be derived from either approach. As mentioned, each individual situation is unique, with different factors affecting the eventual decision. Obviously, benefits must be assessed on the basis of capital and operating costs, productivity, ease of operating and quality characteristics of products.

### 7.1 Discussion of Single and Two Stage Classification in the Grinding and Classification of Cement

While two stage classification has its advantages in terms of overall classification efficiency and productivity, there are factors apart from engineering considerations that are considered negative. These are:

- In two stage classification, two classifiers need to be controlled at all times.
- Any upset in the first stage may also affect the second stage.

As the second stage classifier operates with material rejected from the primary classifier, i.e. the mill circulating load, control of the second classifier may be difficult, if the system is subject to fluctuation in the volume of mill discharge. A change in feed rate to the classification system is likely to have a more pronounced effect in the second stage. This will be particularly noticeable if there is a large drop in the feed rate to the classifier. High efficiency air classifiers can be more sensitive to a change in feed rate than less efficient conventional separators.

As has been documented in section 6.0, feed rate has a significant impact on product quality.

In general, this can be quantified as follows:

- At constant air flow and rotor speed, an increase in feed rate will result in a finer product and lower classification efficiency.
- At constant air flow and rotor speed, a reduction in feed rate results in a coarser product and increased classification efficiency.

The effect, particularly at low feed rates, is more pronounced on products that are controlled on the basis of surface area i.e. Blaine than products controlled on the basis of top size, i.e. the coarsest particle. Despite the fact that high efficiency air classifiers have an excellent capability of controlling product quality, they are sensitive to upsets in feed rates.

The full benefits of two stage "series" classification can only be achieved if all operating conditions and other parameters that may affect product quality are controllable. One method of improving control in the classification process (but a costly one) would be to install a surge bin between primary and secondary classifiers, to provide a controlled feed rate to the second stage classifier.

Another concept in two stage classification, which has been applied succesfully in a non-cement application, is to use the first stage classifier to produce a clean reject material rather than a finished product. The rejects, being reasonably free of product sized material, are returned to the mill. The classified product, (containing a significant amount of oversize), is then re-classified in the second "high efficiency" classifier, with the oversize returned to the mill or back to the first classifier.

This concept may be utilized in cases where the primary classifier is not able to produce the required product efficiently. Usually, such a classifier can be operated at high efficiency producing a coarser product. The concept is to operate each classifier at its most efficient level, producing high volumes of intermediate product in the first classification stage. The benefit of this approach of two stage classification is, that only the second classifier is subject to rigorous process control.

There is only limited literature on the practical applications of two stage classification in the cement industry. Much of the research on two stage air classification has been pioneered by Dr. R.T. Hukki, at the Technical Research Centre in Otaniene, Finland. His findings and conclusions were published in 1977 in Zement Kalk Gips.(C-9)

Other articles on the subject have been published by: K. Heiskanin(C-6), "Two Stage Air Classification - Why?, Larox News 1980 and H. Eronin H.(C-5), "How Two Stage Classification affects Cement Grinding at the Ciment Lafarge Plant, Limay, France".

Information has been extracted from the latter article, to demonstrate the comparison between single and two stage air classification. Actual performance of the classifiers employed is considered below the achievable level for high efficiency classifiers and is not to be interpreted as (necessarily) being representative of high efficiency air classification.

Data as extracted from the article is shown in tabular form.

The system used in the tests was a three compartment mill 12 meters long, 2.2 meters in diameter with a 580 kW drive.

The first and second mill chambers were charged with balls, the third compartment with cylpebs.

Two Larox, EC 10 separators were employed to conduct 3 types of tests, the mill with: 1 separator; b) two separators in parallel; and c) two sepators in series. Some 150 tests runs were made. Results of the three tests published in the article are examined and discussed.

Data as reported is shown in Tables 7.1-1, 7.1-2, and 7.1-3.

## TABLE #7.1-1

### OPERATIONAL DATA WITH SINGLE STAGE CLASSIFICATION WITH ONE (1) SEPARATOR IN OPERATION

INPUT TO GRINDING CIRCUIT 12 TPH

| | MTPH | Blaine CM$^2$/Gram | % -32 Micron | % -100 Micron | % Efficiency at 32 Micron |
|---|---|---|---|---|---|
| MILL DISCHARGE | 25.4 | 2770 | 49.0 | 88.6 | |
| SEPARATOR FINES | 11.3 | 3530 | 63.25 | 93.0 | 53.9 |
| SEPARATOR COARSE | 13.4 | -- | 38.8 | 84.7 | |
| DUST | 0.7 | -- | -- | | |
| TOTAL PRODUCT | 12.0 | | | | |

Classifier efficiency was calculated at 32 micron and reported to be 53.9%. The recirculating load was calculated as being 118.6%. Unfortunately, the particle size of the dust product was not determined, but is assumed to be similar to the product.

In test 2, two identical separators were operated in parallel. Mill feed was 16 tph when the mill-classification system was in a "steady state" condition. The mill discharge was coarser than at the 12 tph mill feed rate. This resulted in a build up of circulating load.

**TABLE 7.1-2**

TWO SEPARATORS OPERATING IN PARALLEL

INPUT TO GRINDING CIRCUIT 16 TPH

|  | MTPH | Blaine $CM^2$/Gram | % -32 Micron | % -100 Micron | % Efficiency at 32 Micron |
|---|---|---|---|---|---|
| MILL DISCHARGE | 49.1 | 2090 | 44.5 | 86.6 |  |
| #1 SEPARATOR FINES | 6.7 | 3280 | 68.4 | 95.7 | 46.0 |
| #1 SEPARATOR COARSE | 17.4 | -- | 34.3 | 82.3 |  |
| #2 SEPARATOR FINES | 6.5 | 3320 | 70.0 | 95.3 | 50.9 |
| #2 SEPARATOR COARSE | 15.7 | -- | 32.3 | 82.3 |  |
| DUST | 1.7 | -- | -- | -- |  |
| TOTAL PRODUCT | 16.0 | 3270 | 63.1 | 92.84 | 52.3 |

The calculated circulating load is 207%.

Feed rate to each of the two separators is the same as in the previous test using one separator. Mill discharge is significantly coarser. The likely reason is the higher mill feed rate of 16.0 tph versus 12 tph as in test 1. Total mass flow through the system increased by 93% to 49.1 tph.

In Test 2, the classifier efficiency was similar to Test 1, but is considered low. Blaine surface area of the two products produced in Test 2 are lower than in Test 1 (3270 versus 3530). This indicates that product fineness is affected by the coarseness of the mill discharge. Grinding efficiency at the higher mass flow appears to be lower than at the lower rate.

In comparing the volumes of -32 micron material in the mill discharges, we see that in Test 1 the volume of -32 micron material passing thru the separator is 12.45 tph. In Test 2, the volume is 21.85 tph.

It is interesting to note that classified product from Test 1 contained less -32 micron material, i.e. 63.25%, at a Blaine of 3530 $cm^2$/gram, while products in Test 2 contained 68.4% and 70.0% passing 32 micron, but a Blaine of only 3280 $cm^2$/gram and 3320 $cm^2$/gram. This points to a lack of fine material in the mill discharge.

In Test 3, the separators were operated in series rather than in parallel. All of the mill discharge was classified in the first separator with rejects being reclassified in the second separator. Mill feed at 16 tph, was the same as in test 2.

Test results are given in Table 7.1-3.

# TABLE # 7.1-3

## OPERATION DATA OF A TWO STAGE CLASSIFICATION CIRCUIT WITH SEPARATORS OPERATING IN SERIES

INPUT TO GRINDING CIRCUIT 16 TPH

| | MTPH | Blaine CM$^2$/Gram | % -32 Micron | % -100 Micron | % Efficiency at 32 Micron |
|---|---|---|---|---|---|
| MILL DISCHARGE | 27.4 | 2670 | 58.5 | 92.6 | |
| #1 SEPARATOR FINES | 8.4 | 3845 | 74.5 | 96.6 | 54.3 |
| #1 SEPARATOR COARSE | 18.3 | -- | 46.6 | 91.2 | |
| #2 SEPARATOR FINES | 6.9 | 3165 | 65.0 | 97.2 | 48.5 |
| #2 SEPARATOR COARSE | 11.4 | -- | 36.8 | 87.0 | |
| DUST | 0.7 | -- | -- | -- | |
| TOTAL PRODUCT | 16.0 | 3520 | 69.1 | 97.2 | 79.4 |

The calculated mill circulating load was 71.3%

Combined discharge in Test 3 was similar to Test 1, in volume and fineness. The main difference is that in Test 1, total product was 12 tph while in test 3, total product was 16.0 tph, an increase of 33.3%.

It should be noted that separator #1 was operated under conditions that gave a higher Blaine, i.e. 3845 cm$^2$/gram to compensate for the lower (as expected) Blaine of 3165 cm$^2$/gram of separator #2 product.

In comparing all three tests, the outstanding feature is the way the mill performed with two separators in series as compared to two separators in parallel.

In Test 2, there was a high circulating load at the 16 tph mill input. Mill discharge was also lower in Blaine surface area and in percentage of material finer than 32 micron.

In Test 3, the build up of circulating load (at steady state conditions) did not occur and mill grinding efficiency was obviously much better than in test 2.

In either case, when operating with two classifiers, 16 tph of product was produced. Product quality, with respect to Blaine, was good with the classifiers operating in parallel, but was much better with classifiers operating in series.

Operating with only one classifier required a lower mill feed. Any increase of mill feed would have resulted in a reduction in grinding efficiency, a build up in circulating load and corresponding drop in separator efficiency.

Conclusions are, that with only one separator operating, the system is capable of producing 12 tph of acceptable product. With two classifiers, the system is capable of producing 16 tph of product. However, with the classifiers in parallel product quality was below the desired level and grinding efficiency is adversely affected. With the classifiers in series, product is of good quality and grinding efficiency is apparently higher.

The following comments are believed to be in order in interpreting test resuls as given in the article. It can be argued that for instance in the case of Test 1, the classifier efficiency is low because the classifier is operated at a feed rate above the effective classifier capacity. Therefore, a case could be made, that in order to match mill potential with classifier capacity, a larger or an additional classifier would be required to operate the system effectively.

This illustrates that it is important to match mill capability with sufficient classifier capacity. So, if the classifiers operate efficiently, the mill can also operate at its best potential.

It is the authors opinion that "two stage" air classification in cement production is viable. If the installed classifier is not operating satisfactorily, a second stage can be an effective means of improving system efficiency.

As noted, the choice of either replacing an existing low efficiency classifier with a high efficiency classifier (matched to the mill) or to add a high efficiency classifier (if space is available) as a second stage to the system, requires extensive testing to provide data on which a decision can be based.

## 8.0 SPECIFIC EXAMPLES OF IMPROVED ENERGY UTILIZATION IN CEMENT PRODUCTION RESULTING FROM USING "STATE OF THE ART" AIR CLASSIFICATION EQUIPMENT

During the last decade many cement producers have either replaced or retro-fitted their air classification systems, while new cement plants built are equipped with the new type of high efficiency air classifiers.

In virtually all cases, utilization of high efficiency air classification resulted in productivity gains at the same kWh power input and thus reduced the kWh/t of cement produced.

This is largely the result of a significant increase in air classification, demonstrated by higher yields of specified Blaine surface area per ton of mill discharge.

Rejects from high efficiency air classifiers are cleaner, i.e. contain lower volumes of "product quality" material. Coarser classifier reject material returned to the grinding mill, improved grinding efficiency and allowed higher feed rates to the mill.

Lesser amounts of fines in the reject stream favours increased transportation through the mill, because of better flow characteristics. Better flow potentially reduces the risk of overgrinding, the creation of excessive fines and fines agglomeration during grinding, all which lead to poor dispersion of the material to be air classified.

Overall improvements vary from case to case, as other conditions, such as mill design, feed characteristics, type of discharge grates, type of grinding media, and use of grinding aids, will affect performance of a grinding-classification system.

Improvements achieved through the installation of high efficiency air classifiers in cement grinding circuits have been well documented and publicized either in trade journals, or as the subject of technical papers at various conferences.

Manufacturers of air classification equipment, in collaboration with cement producers, have measured and documented productivity gains and reduced energy consumption per ton of cement produced.

In this section of the study, relative data, based on published information of measured improvements, is summarized and discussed. Where possible, a direct comparison of productivity and power consumption is made between operating with conventional air separation equipment and the new high efficiency air classifiers.

Only a cross section of results were provided, including several makes of high efficiency classification equipment. In all cases the observed improvements are significant, but vary from case to case. This must not be interpreted as being a comparison of different air classifiers, but rather as a comparison of complete systems. An accurate comparison of air classifiers can only be made, if a given grinding system is systematically operated with several different classification units.

It is not the intention of the author to make comparisons between air classifiers, but simply to highlight published data available at time of writing. Exclusion of any air classifier type or manufacturer was not done purposely, but strictly because data was not available.

Following are a few case histories on the effect of high efficiency air classification on productive capacity and energy consumption.

## Tunnel Cement - Padeswood Mold, CLYWD U.K.

This specific comparison is not between conventional and high efficiency air classification but rather a comparison between an "open circuit" grinding system and the same mill equipped with a high efficiency air classifier operated in closed circuit. The installation was completed and commissioned in April of 1985.

The mill, three (3) compartments, 11.5 feet in diameter and 35 feet long, is driven by a 1700 kW, 2700 HP motor.

This mill, in open circuit, produced 42 tonnes of type 1 cement at 3600 Blaine, using the entire 1700 kW of the drive plus 243 kW for the auxiliary equipment. This is equivalent to 46.26 kW/ton at a cement discharge temperature of 218°F. No cement cooler was used in the system.

Tunnel Cement specified a minimum production rate of 48 tonnes per hour at 3600 Blaine with a maximum finished product temperature of 160°F and no loss of strength.

The mill was equipped with a Sturtevant, SD-80, high efficiency air classifier with auxiliary equipment. Total installed kW for the classifier and auxiliary equipment was 335 kW including the 246 kW drive for the circulating fan.

The total kW of the system was 2035. After two weeks of operation and fine tuning the mill system, production reached a high of 50 tonnes per hour, but was purposely reduced to 48 tonnes per hour. 48 tonnes/hr is equivalent to 42.40 kW/tonne which is a reduction of 3.86 kW/tonne compared to the open circuit system. Product discharge temperature was 138°F, Blaine surface area 3680 $cm^2$/gram and the classifier reject Blaine was 930 $cm^2$/gram.

In 1986, the mill was upgraded to 1850 kW which increased type 1 cement output to 55 tonnes per hour at a Blaine of 3600 $cm^2$/gram. Net energy consumption was 39.73 kW/tonne increasing the total reduction between the open circuit system and the new closed loop circuit with the high efficiency classifier to 6.53 kW/tonne of cement or an energy savings of 14.12%.

This analysis effectively illustrates the effect of close circuiting a conventional open circuit grinding system with a high efficiency air classifier.

## Keystone Portland Cement Company - Bath, Pennsylvania

Reference C-9 - R.H. Faust, Keystone Cement and I.V. Klumper, Sturtevant Inc., Boston, MA.

In 1984, Keystone Portland Cement desired to increase its cement production. The milling system consisted of six 7 foot diameter x 42 foot long tube mills, each mill consuming 700 H.P. (521 kW per hour).

Three of the mills were operated in closed circuit with an 18 foot diameter conventional Sturtevant whirlwind air separator. Two other mills were closed circuited with a 14 foot diameter Sturtevant separator. The sixth mill was on standby.

It was decided to upgrade the two mills by replacing the 14 foot diameter conventional separator with a Sturtevant, SD-80, (side draft) high efficiency air classifier. The SD-80 would be capable of processing the discharge of the two or possibly three of the mills and also provide sufficient cooling to permit removal of the existing cement cooler.

The system installed employed product collection with cyclones. The SD-80 high efficiency air classifier was 8 feet in diameter and 13 feet high, equipped with a 12-16 HP variable speed drive which allows various types of cement to be produced.

Results obtained are given in Table 8.1. The figures indicate a significant increase in production rate, higher cement strengths, cleaner rejects, reduced circulating load and energy savings of 10-25%.

## TABLE 8.1

### KEYSTONE CEMENT - BATH, PENNSYLVANIA

### COMPARISON OF NEW CLASSIFIER AND STANDARD AIR SEPARATOR

BASED ON TYPE 1 CEMENT UNLESS INDICATED OTHERWISE

| **PARAMETER** | **SD-80** | **14' WHIRLWIND** |
|---|---|---|
| PRODUCTION RATE, (STPH) | 40 (3 MILLS) | 23 (2 MILLS) |
| CEMENT STRENGTH, psi: | | |
| AFTER 3 DAYS | 3650 | 3560 |
| AFTER 7 DAYS | 4560 | 4480 |
| AFTER 28 DAYS | 5470 | 5310 |
| SPECIFIC SURFACE, ($cm^2/g$ BLAINE): | | |
| TYPE I CEMENT | 3610 | 3850 |
| TYPE III CEMENT | 5250 | 5000 |
| FINENESS, (% PASSING 325 MESH): | | |
| PRODUCT | UP TO 99 | UP TO 97 |
| TAILINGS | 18 | 58 |
| CIRCULATING LOAD, % | -150 | 320-400 |
| EFFICIENCY, % | 75-85 | 35-40 |
| ENERGY SAVINGS, % | 10-25 | - |
| COOLING DONE IN | CLASSIFIER | CEMENT COOLER |

## Gulf Coast Portland Cement - Houston, Texas

Gulf Coast Portland Cement is a cement producer, grinding purchased clinker in several finish mills. Clinker purchased from several sources is blended to achieve a reasonably uniform quality. Due to competitive situations requiring higher Blaine surface areas and increased clinker hardness, productivity had declined by approximately 15%.

In 1983, Gulf Coast Portland Cement, in an effort to become economically competitive, reduce energy requirements, and to improve cement quality, decided to replace their two conventional 18 foot diameter air separators, (part of the #2 and #3 finish mill grinding circuits), with a single high efficiency Fuller O'Sepa air classifier.

To reduce project costs, the new separator was installed using most of the existing auxiliary equipment. Due to the O'Sepa's small physical size, it was possible to install the new air classifier without having to remove the old separators. Existing product collectors were of sufficient capacity and were retained in the system. The new classifier was able to accept discharge from both grinding mills and the rejects were split and returned equally to both mills.

The original circuit of the two mills, auxiliary equipment and cement coolers had a power consumption of 3115 kW. In this circuit in order to achieve 90% passing 325 mesh (45 micron) it was necessary to grind to a 4000 Blaine.

After the installation of the new O'Sepa air classifier, it was possible to grind to a 3200 Blaine and achieve 93.5% passing 325 mesh (45 micron) screen.

As a result of the improved Blaine to 325 mesh ratio, cement strength increased by 5% at one and three days, 10% at 7 days and 5% after 28 days.

Productivity after commissioning and adjustment increased by 14-18%. Power consumption was reduced by 7%, from 3115 kW to 2900 kW. Major power savings resulted from elimination of the cement coolers plus a reduction of the ball charge.

This case history shows not only the effect of high efficiency air classification on productivity improvement and energy consumption, it also demonstrates the effect on the quality characteristics of the cement product.

### Lehigh Portland Cement Company - Mason City, Iowa

Lehigh Portland Cement was the first North American cement producer to install an N-2000 model O'Sepa high efficiency air classifier in September of 1984.

The installation was made without removal of the existing conventional air separator. Cyclone collectors and a dust collector from the existing system were also retained. The complete changeover was completed with only two weeks of downtime.

As part of the overall project, the mill ball charge was regraded, water spray's added, and grinding aids employed.

Table 8.2 shows the pertinent data of productivity and corresponding mill kWh/tonne, total power consumption and the relationship between Blaine and percent passing 325 mesh (-45 micron) screen.

The before and after comparison showed dramatic increases in productivity, reduced energy consumption and a reduction in Blaine surface area while improving the percentage passing 325 mesh (-45 micron) screen.

## TABLE 8.2

### 15'0 DIA x 28'0 LONG 3500 HP FINISH MILL CIRCUIT
### BEFORE AND AFTER N-2000 MODEL O'SEPA ADDITION

### PARTIAL DATA SUMMARY

| DATE | TPH | MILL kWh/t | TOTAL kWh/t | +30 MICRON | -45 MICRON | BLAINE |
|---|---|---|---|---|---|---|
| JUN 84 | 65.9 | 39.3 | 52.5 | 25.7 | 89.1 | 3809 |
| REGRADED BALL CHARGE, ADDED WATER SPRAY & GRINDING AID EMPLOYMENT | | | | | | |
| AUG 84 | 77.7 | 33.3 | 44.5 | 24.8 | 88.7 | 3679 |
| INSTALL O'SEPA, 2 WEEKS DOWNTIME | | | | | | |
| SEP 84 | 85.0 | 30.5 | 39.7 | 23.1 | 92.7 | 3700 |
| INSTALL AIR RECYCLE DUCT TO INCREASE O'SEPA AIRFLOW | | | | | | |
| OCT 84 | 90.7 | 28.8 | 38.7 | 18.1 | 94.4 | 3577 |

## Capitol Aggregates Inc., - San Antonio, Texas

Capitol Aggregates Inc. installed an O'Sepa high efficiency air classifier in 1985. Data received in September of 1985 indicated significant improvement in productivity. No information was provided on details of the conversion or on energy reduction. The data on increased productivity, assumedly at the same total energy consumption indicates the power savings to be considerable.

Available data is shown on Table 8.3.

# TABLE 8.3

CAPITOL AGGREGATES, INC.
SAN ANTONIO, TEXAS

O'SEPA FINISH MILL SYSTEM
EFFECT OF O'SEPA ON PRODUCTION

| | BEFORE O'SEPA | AFTER O'SEPA |
|---|---|---|
| TYPE 1 | 2800 BLAINE<br>55 TPH | 3600 BLAINE<br>80 TPH |
| TYPE II | 3400-3500 BLAINE<br>55 TPH | 3400-3500 BLAINE<br>70 TPH |
| TYPE III | 5100 BLAINE<br>25 TPH | 4600-4800 BLAINE<br>40 TPH |

Sol Financiera y Minerva S.A. - Malaga, Spain
Reference C-1

The above company was the first to install an F.L. Smidth Sepax high efficiency air classifier in August of 1984. The Sepax, Model 265, replaced a conventional air separator with a built in fan and an internal air circulation.

The grinding system to which the Sepax classifier was added consisted of an F.L. Smidth Unidan 3.2 meter dia. x 12 meter long mill with a 1600 kW drive. Product collection from the classifier was by baghouse collector vented to atmosphere.

Improvements in productivity, reduction in energy consumption, and product quality are shown on Table 8.4.

# TABLE 8.4

SOL FINANCIERA Y MINERVA S.A.
MALAGA, SPAIN

## SYSTEM PERFORMANCE AFTER INSTALLATION OF A SEPAX 265 HIGH EFFICIENCY AIR CLASSIFIER

| | SEPARATOR TYPE | |
|---|---|---|
| | SEPAX | CONVENTIONAL |
| OUTPUT mtph | 57 | 44 |
| SPECIFIC ENERGY CONSUMPTION | kWh/mt | kWh/mt |
| MILL MOTOR | 28.1 | 36.4 |
| SEPARATOR | 0.1 | 2.2 |
| SEPARATOR FAN | 2.7 | - |
| TOTAL | 30.9 | 38.6 |
| % RETAINED ON 325 MESH (45 MICRON) SCREEN | 10 | 13 |

The only other recorded change in the system was an adjustment in the ball charge.

Productivity increased by approximately 30% while the net energy consumption per tonne decreased by roughly 20%. It was considered that part of the achieved improvements were a result of optimizing the overall milling system.

## Krupp Polysius - Reference G-17

Data on conversion of cement grinding mills with Krupp Polysius Cyclopols were obtained from an internal publication dated December 18, 1985. Reference is made to several conversions without identifying the company or its location.

One of the examples given in this publication is of a conversion of a cement grinding plant in Southern Germany. In this instance, two turbo-separators were replaced with one Krupp Polysius Cyclopol 42/4 model high efficiency unit.

This separator was used in conjunction with a mill of the following dimensions and drives.

Mill Size - 3.6m dia x 14.0m long
Chamber #1 - 5.0m long
Chamber #2 - 8.5m long

Drive Motor - 1900 kW

### Performance

|  | Before Conversion | After Conversion |
|---|---|---|
| Output mtph | 38.0 | 45.7 |
| Blaine $cm^2$/gram | 4100-4300 | 3910 |
| Specific Power Cons. |  |  |
| Mill kWh/tonne | 48.7 | 40.5 |
| Separator | 3.6 | 5.7 |
| **Total** | 52.3 | 46.2 |

## Presa S.P.A. Robilante Plant - Italy

In this plant, an existing turbopol separator was replaced by a Cyclopol 32/4 high efficiency separator. In 1985 information on mill system, productivity, and energy consumption before and after conversion is given below.

### Mill Data

Mill Size - 3.4 meter diameter x 12.5 meter long
Drive - 1750 kW

### Mill Capacity

| | Before Conversion | After Conversion |
|---|---|---|
| Cement Type R2 mtph | 39 | 47.3 |
| Blaine cm$^2$/gram | 3800 | 3770 |
| Capacity Increase | - | 21% |
| **Energy Consumption kWh/tonne** | | |
| Mill | 44.8 | 33.9 |
| Total System | 47.0 | 37.5 |
| Energy Savings | - | 25% |

Additional summary data on various other conversions from conventional separators to the high efficiency are given below.

Gebr. Wiesbock & Co. G.M.B.H., Rohrdorf, W. Germany. Conversion from two turbo separators to a single cyclopol 28/4.

Mill Data

| | |
|---|---|
| Size | 2.8m dia x 12.0m long |
| Drive | 1100 kW |

Mill Capacity

| | Before Conversion | After Conversion |
|---|---|---|
| Cement Type | P.L. 45 F. | P.L. 45 F. |
| (tph) | 17 | 25 |
| Blaine ($cm^2$/gram) | 4300-4500 | 4000-4300 |
| Capacity increase at same blaine | - | 31% |

Total Energy Consumption

| | Before Conversion | After Conversion |
|---|---|---|
| For Mill | 60 kWh/tonne | 44 kWh/tonne |
| For System | 71 kWh/tonne | 51 kWh/tonne |
| Energy Savings* | - | 28% |

* Energy savings based on cement of same strength.

These actual examples of conversions from conventional to high efficiency air classifiers leave no doubt as to their effectiveness in improving productivity and in most cases at significantly lower energy consumption.

While these are important as they relate directly to cost, other factors should not be overlooked. In many cases there is also an increase in cement quality due to better control over particle size distribution. High efficiency air classifiers are simpler to control and most types can be quickly adjusted to produce a different quality of cement.

Undoubtedly, further improvements and advances in separation technology will be made in the future. The technology of grinding classification is still the subject of research and development. Of particular interest, is improving the ability to control the size distribution of cement products.

## 9.0 CONCLUSIONS

Air classification is now accepted as an important unit operation in the processing of fine mineral powders, cement and metallic powders.

Recognition of the importance of air classification as a technology, rather than a means to an end, has brought about significant improvements in overall system productivity and efficient energy utilization in grinding classification systems.

As energy costs became a significant factor in communition, effective use of energy and energy conservation became the driving force behind the optimization of grinding and classification systems.

In recognizing the importance of efficient air classification, it became clear that significant advances in productivity and reduction in energy consumption could be achieved by developing air classification systems based on the theoretical factors such as particle dynamics, etc. that govern the classification process.

A combination of theory coupled with innovative design has led to the development and implementation of high efficiency air classification equipment in the mineral, cement, and other industries.

The need for improved air classification was not only spurred on by the need to improve energy consumption. It was also driven by the need for improvements in product quality, such as product uniformity, and for finer and better controlled products.

Great strides have been made in the development of air classification equipment capable of producing products with a five (5) micron top size fineness and a ten (10) micron every day product.

In the cement industry, the development of the high efficiency air classifier has been of significant importance and benefit. High efficiency air classification has contributed prominently to the increased productivity of cement-grinding classification systems with a corresponding reduction in energy consumption per ton of cement produced.

Examples as given in this study show that savings are indeed of major proportion.

With improved understanding of the importance of air classification and the application of theoretical factors that govern air classification, it is now possible to design and construct air classification equipment far superior to conventional air classifiers. The trend, started in the 1970's, is expected to continue and further advances are forthcoming. Future improvements are likely to be the result of better design features, taking full advantage of the aerodynamic factors governing the air classification process.

While it is clear, as has been demonstrated by actual testing or by reviewing data extracted from the literature, that high efficiency air classification is a significant step forward, caution is advised with respect to their operation and control. In general, the high efficiency air classifier is more sensitive to changes in the process, particularly feed rate. To achieve the full potential of high efficiency air classification, requires a highly effective means of controlling the feed rate to the classifier. But, this is an engineering problem that can be readily resolved.

The following are the various factors that, if properly attended to, will achieve optimum results:

- Material to be classified must be well dispersed and free of agglomerates, which can be achieved by use of appropriate grinding aids, flow aids or chemical dispersants.

- The classifier also must have the ability to disperse the feed material.

- Optimization of the feed rate, which combined with the proper air flow, air particle velocity and rotor speed, will result in optimum classification efficiency.

- Control of air flow and velocity. However, it must be noted that changes in air density, due to changes in air temperature, may have a (minor) effect on product quality.

The following are process variables that will affect product quality for a given rotor speed and air flow and prescribed solutions:

- An increase in feed rate will result in a finer product and lower classifier efficiency.
- A decrease in feed rate will result in a steeper size distribution and a corresponding increase in efficiency.
- Within the defined operating range, classifiers will tolerate a change in feed rate without any measurable effect on product quality. This is sometimes called "the effective feed rate plateau" or "effective feed rate operating range".
- If the feed rate is changed to a level above the effective feed range, and the product becomes finer, the counter action is to reduce rotor speed. Similarly, rotor speed should be increased, if the feed rate is below the effec-

tive operating range. The other is of course to bring the feed rate back in line.

- If feed to the classifier, i.e. the mill discharge, becomes coarser, then for the same air flow, feed rate and rotor speed the product becomes coarser.
  Two possible counteractions are: a) increase rotor speed or b) increase feed rate. The first will result in a finer product, but at a slight loss in classifier efficiency. The second, will also result in a finer product. Classifier efficiency may not change if the new feed rate is within the optimum feed rate range for this feed quality.
- If feed to the classifier, i.e. mill discharge, becomes finer then, at appropriate air flow and rotor speeds, the product will be finer. This can be controlled by either reducing rotor speed or feed rate.

It is important that these various factors are understood. It is suggested that prior to commisionning a classifier, a series of tests be conducted to evaluate the effect of individual events; such as an increase or decrease in feed rate on product quality, the effect of coarser or finer feed on product quality; and to identify the steps that must be taken to maintain product quality and classifier efficiency.

Corrective action is usually based on results of manual sampling and off-line product testing in the plant's laboratory. This is time consuming, and by the time analysis are completed the condition(s) that caused the system to go off track may no longer exist. Any corrective action is, thus after the fact, and may cause a new upset in the system. For a system to operate at its optimum level of efficiency and product quality, it is necessary to monitor mill discharge, classifier product and classifier rejects or particle size distribution, surface area, etc.

Each of these tests are important, however, product quality is paramount and should be checked with greater frequency than the others. Rejects, returning from the classifier are secondly in importance, as they provide a measure of classifier efficiency. It is important to take all samples simultanously, rather than at different times. Automated sampling systems are of great assistance.

Obviously, the ideal solution would be an automated sampling system with online automated size analysis and subsequent computer control of the system, including the grinding mill. Such systems have been developed, however, their practical use has not yet been fully developed, for use in dry grinding operations.

Another control or measuring device, that may be utilized with success, is the "in line impact flow meter". These units can be effective, particularly on the rejects stream returning from the classifier to the mill. These units work well, if flow is constant and not subject to large surges. Information from this type of flow measuring device can be computer analysed and highlight developing trends.

A similar flow measuring device can be installed on the product side of the classifier. This provides the ability to monitor the system with respect to product and oversize volume, which can be very helpful in analysing process conditions.

## 9.1 POSSIBLE FUTURE TRENDS IN HIGH EFFICIENCY AIR CLASSIFICATION

As has been learned from technical literature and from actual testing, the geometry of the classifier section of a separator plays a significant role in achieving sharp cut points.

Smaller air classifiers because of their size and their ratio of classifier to rotor diameter are capable of producing finer products than larger diameter classifiers. This is similar to wet cyclones, where cyclone diameter is the governing factor in particle separation. Large diameter cyclones produce coarse particle separation, whereas small diameter cyclones make fine particle separations.

Of interest, is that while small diameter classifiers have the ability to produce fine products, they can also produce coarse products at very high efficiency, but at lower effective feed rates, as discussed in Section 6.0.

Future trends in air classification of very fine mineral powders may follow the same route as hydrocyclones, i.e. multiple classifiers in clusters, similar to small diameter cyclones.

Present trends have been to use single large classifiers matched to mill capacity, rather than using multiple classifiers. By clustering a number of classifiers, product collection could either be by individual cyclones, by one large cyclone, or by one large dust collector.

While such a development would be advantageous in producing several fine mineral products simultaneously, adaptation of such a concept in the cement industry is not likely. The main reasons are the increased process and quality control requirements and high costs.

New developments in air classifier equipment are likely to continue. Changes in concept from the current types, that operate on the principal of centrifugal and drag forces to types using the aerodynamic properties of particles are under development. One such classifier operates on the COANDA effect, the same force that provides lift to an airplanes wings, enabling it to fly. Such a classifier has been developed at the University of Toronto by Professor B. Atkin. The prototype is designed to produce as many as five products from a single feed material. A similar classifier has been developed in Japan and has been commercialized.

Classifiers of this type are not likely to find wide commercial applications as they are best suited for processing relatively small volumes of material.

The cement industry is rapidly converting from conventional air separators to high efficiency units and all new plants will be so equipped. Future refinements of classification equipment in the cement industry will be in the area of design and control features, rather than changes in air classification concepts.

Implementation of "state of the art" air classifiers in the cement and metallic mineral has resulted in significant improvements in system productivity, reduced energy consumption, improved product quality, greater operating flexibility system control and the ability to produce extremely fine products.

# AIR CLASSIFICATION - BIBLIOGRAPHY

## GENERAL ARTICLES

1. De Silva, S.R., Centrifugal Air Classification for the Production of Fine Powders. Journal of Powder and Bulk Solids Technology No. 2, 1978, pp. 3-12.

2. Lange, K. New High Efficiency Air Classifiers Spiral, Impeller and Cross Flow Classifiers. Aufbereitings-Technik, No. 1, 1980, pp. 15-22.

3. Klumpar I.V., Currier F.N., Ring T.A., "Air Classifiers". Chemical Engineering March 3, 1986, pp. 77-92.

4. Worral, W.A., Vesilind P.A., Testing and Evaluation of Air Classifier Performance. Resource Recovery and Conservation No. 4, 1979, pp. 247-259.

5. Bernotat, S., Gregor, W., Some Aspects About the Separation in a Cross-Flow Air Separator. Chemical Engineering Science, Vol. 33, 1978, pp. 751-787.

6. De Silva, S.R., Developments in Air Classifier "Theory & Practice. I. Chem. E. Symposium, Series #69, pp. 387-410.

7. Prem, H., Prior M.H., Some Recent Developments in Size Reduction and Air Classification. I. Chem. E. Symposium, Series #63 D2, pp. 1-19.

8. Vesilind, P.A., Henrikson, R.A., Effect of Feed Rate on Air Classifier Performance. Resources and Conservation #6, 1981, pp. 211-221.

9. Hukki, R.T., Karhunen J., Lindsberg R,. Practical Research on Two Stage Air Classification. Zement-Kalk-Gips No. 7, 1977, pp. 314-322.

10. Dunn, M.R., A Method for Analyzing the Performance of a Mechanical Air Separator. World Cement, Oct. 1985, pp. 326-332.

11. Suh, T.S., et al. Mechanism of Classification in a Sturtevant Type Air Classifier. Fluid-Solid Interaction, Vol. II, pp. 131-135.

12. Lauer, O., A Measuring Method to Characterize the Separation of Air Classified Fine Materials. Chem. Eng. Process 18, 1984, pp. 275-282.

13. Heidiger, A., Air Classification in Theory and Application. Internal Publication, Alpine American Corp., Natick, Massachusetts.

14. Dunn, M.R., An Innovation for the Efficient Production of Superfine Materials. Internal Publication, C.E. Raymond, Combustion Engineering Inc., Chicago, Illinois, 60606.

15. Alpine American Corp. Air Classification Seminar. A Seminar Course Book, Alpine American Corp., Natick, Mass.

16. Hukki, R.T., Fundamentals of the Closed Grinding Circuit. E.M.J., April 1979, pp. 102-109.

17. Finish Mill Upgrade Through Separator Refits. A Comparison of Achieved Performance. Krupp Polysius - Internal Publication, Dec. 18, 1985, Krupp Polysius A.G., Beckum, W. Germany.

18. Donaldson Company Inc., How to Rate Air Classifiers. Donaldson Company Inc., Bulletin 9810-5, 1972.

19. Catlin, A.W., Universal Road Machinery Co., Formulas Applicable to Air Separation. Internal Publication, Universal Road Machinery Company, New York, N.Y.

# AIR CLASSIFICATIONS

## BIBLIOGRAPHY

### CEMENT CLASSIFICATION

1. Joergenson, S.W., Develop High Efficiency Air Separator for Cement Grinding Systems. Pit and Quarry, July 1985, pp. 36-40.

2. Von Rock, H., The Separating Performance of Air Separators and its Effect on the Results of Closed Circuit Grinding. Cement-Kalk-Gips No. 11, 1977, pp. 564-566.

3. Onuma, E., Furukawa T., O-Sepa, A New High Performance Air Classifier. World Cement, Jan/Feb 1984, pp. 13-22.

4. Klumpar, I.V., Zoubov, N.N., New Sturtevant High Efficiency (S.D.) Classifiers, Keystone Cement. World Cement, October 1985, pp. 302-307.

5. Eronin, H., How Two Stage Classification Affects Cement Grinding at the Cement Lafarge - Limay Plant, Limay, France. Larox News, Larox, Finland.

6. Heiskanen, K., Two Stage Air Classification - Why? Larox News, No. 2, 1980.

7. Blacyk, G., Eickholt H., Schneider L.T., Finish Grinding Plants - Opportunities for Modernization. Internal Publication, Krupp Polysius A.G., Beckum, West Germany.

8. Dodson, U.H., Welch P.W., Mardulier, F.J., Finish Grinding, The Grace Umbrella Technique, Part I. Rock Products, June 1974.

9. Foust, H.R., Keystone Portland Cement. Klumpar, I.V. Sturtevant Inc., Boston, MA. Experience with the Sturtevant High Efficiency (S.D.) Classifier, Internal Publication, Sturtevant Inc., Boston, MA.

10. Dunn, M.R., Development of the Raymond High Efficiency Mechanical Air Separator for Improved Cement Quality and Higher Capacity. Internal Publication, 1986, C.E. Raymond, Combustion Engineering, Inc. Chicago, Illinois, U.S.A. 60606.